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FIRE-RELATED INJURIES AND THEIR BURDEN IN FINLAND 2000–2010

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ACADEMIC DISSERTATION

Doctoral dissertation, to be presented for public discussion with the permission of the Faculty of Medicine of the University of Helsinki, in Athena Hall 107, Siltavuorenpenger 3 A, on the 30th of April at 12 o'clock.

Helsinki 2020

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Doctoral Program in Popuation Health

ISBN 978-951-51-6002-7 (nid.)
ISBN 978-951-51-6003-4 (PDF)

Unigrafia Oy
Helsinki 2020

ABSTRACT

Fire-related injuries are among the most devastating injuries. Severe burns and combustion gas poisoning, often associated with residential fires, are responsible for considerable morbidity and mortality.

The aim of this register-based study was to examine the epidemiology of and burden caused by fatal and non-fatal fire-related injuries in Finland from 2000 through to 2010. The study is based on Finnish National Hospital Discharge Register (FHDR, THL), Causes of death statistics and socio-economic background data (Statistics Finland), a sample from the Helsinki Burn Centre, cost of care data (separate acquirement from Helsinki University hospital and Kuopio University hospital, other care providers nationwide as estimates) and health-related social benefits (Kela, Keva). The registers were interlinked deterministically using personal identification numbers. The study is epidemiological and descriptive, in which traditional statistical methods (Poisson regression, linear regression, bootstrap, quantile regression, generalized additive model, Wilcoxon test, Kruskall-Wallis test) were used to describe the data. Additionally, in estimating indirect costs, Human Capital –method was applied. During this study period, in Finland (pop. 5.5 million) there was an average of 99 fire-related deaths per year, corresponding to 18 deaths per million of the population. In most cases the underlying cause of death was combustion gas poisoning (65%), followed by burns (33%) and other miscellaneous injuries. The majority (76%) of the victims were males. The mean age was 52 years for males and 57 years for females. The indirect costs of fire-related deaths and accounting for socio-economic deprivation and decreased productivity reached some EUR 31.1 million per year, ranging between EUR 800,000 for young females and EUR 91,000 for elderly males per person. Additionally, an average of 2,763 potential years of life lost (PYLL) were lost due to premature deaths caused by fire. However, PYLL per person decreased from 34 years in 2000 to 25 years in 2010.

On average, there were some 300 fire-related injury cases per year that led to inpatient care. The main types of injuries recorded were burn injuries (77%), followed by combustion gas poisoning (17%) and other injuries (6%). Most of the victims were males (74%). The mean age was 40 years for males and 50 for females. The incidence of fire-related burns declined, mostly among the young age groups, during the period 1.1.2000–31.12.2009, but that of combustion gas poisonings increased during the same period. The direct average cost for health care was EUR 25,400 for a patient who had sustained a fire-related burn and EUR 3,600 for a patient who had sustained combustion gas poisoning.

The overall annual average direct cost of fire-related injuries was EUR 6.2 million, of which burns accounted for EUR 5.9 million and combustion gas poisonings for EUR 0.19 million. Indirect costs, experienced as productivity losses due to fire-related injuries, reached EUR 28.6 million in the five-year period of 2001–2005, corresponding to an average of EUR 5.7 million annually and EUR 19,070 per person.

Overall, even excluding intangible costs – which were not considered in the present study – as much as EUR 43 million was lost annually due to fatal and non-fatal fire-related injuries, of which the most severe occurred in house fires.

Therefore residential fires accounted for the highest direct and indirect cost of burns, in addition to significant property losses. Considering burden, house fires could be the most beneficial target of preventive measures. Reducing severe injuries among elderly and deaths among young yield highest savings. Cost-effective preventive measures should be seeked after.

TIIVISTELMÄ

Palovammalla voi olla vakavat seuraukset. Tuli ja liekit aiheuttavat usein syviä palovammoja ja myös pahimmillaan tappavia palokaasumyrkytyksiä.

Tutkimuksen tarkoitus oli selvittää liekkivammojen (kuolemaan johtaneet ja ei-kuolemaan johtaneet) epidemiologiaa ja kustannuksia ajanjaksolla 2000-2010 maanlaajuisesti Suomessa. Tutkimus perustuu kansalliseen hoitoilmoitusrekisteriin (HILMO, THL), kuolemansyyaineistoon ja sosioekonomisiin taustatietoihin (Tilastokeskus), palovammakeskuksen otosaineistoon (Töölön palovammakeskus), hoitokustannusaineistoihin (Töölön palovammakeskus, Kuopion palovammakeskus, muu Suomi) sekä terveyteen liittyviin sosiaalietuusaineistoihin (Keva, Kela). Aineistoja yhdisteltiin deterministisesti yksilöllisiä henkilötunnisteita käyttäen. Tutkimus on epidemiologinen ja kuvaileva, jossa perinteisiä tilastollisia menetelmiä (Poissonin malli, lineaarinen regressio, bootstrap, kvantiiliregressio, yleistetty additiivinen malli, Wilcoxonin testi, Kurskall-Wallisin testi) käytettiin aineiston kuvailuun. Lisäksi epäsuorien kustannusten laskennassa käytettiin Human Capital –menetelmää.

Ajanjaksolla 2000-2010 tapahtui keskimäärin 99 palokuolemaa vuodessa, mikä tarkoittaa noin 18 kuolemaa miljoonaa asukasta kohti Suomen 5,5 miljoonaisessa väestössä. Valtaosa (76%) kuolleista oli miehiä. Miesten keskimääräinen ikä oli 52 vuotta ja naisten 57 vuotta. Epäsuorat kustannukset johtuen kuoleman takia menetetystä tuotannosta olivat keskimäärin 31,1 miljoonaa euroa vuotta kohti yhteenlaskettuna. Kustannukset vaihtelivat nuorten naisten lähes 800 000 eurosta iäkkäiden miesten 91 000 euroon, kun otettiin huomioon paloissa kuolevien sosioekonomisesti keskimääräistä väestöä heikompi tausta. Lisäksi menetettiin vuosittain keskimäärin 2763 potentiaalista elinvuotta ennenaikaisten kuolemien seurauksena. Kuolemaa kohti menetetyt elinvuodet vähenivät 34:stä (vuonna 2000) 25:een (vuonna 2010).

Keskimäärin vuosittain tapahtui 300 liekkivammaa, jotka vaativat vuodeosastohoitoa. Valtaosa loukkaantuneista oli miehiä (74%). Miesten keskimääräinen ikä oli 40,4 vuotta, kun se oli naisilla 50,4 vuotta. Liekkipalovammojen ilmaantuvuus väheni kymmenvuotisjaksolla 1.1.2000-31.12.2009. Tätä vastoin palokaasumyrkytysten ilmaantuvuus nousi samalla jaksolla. Liekkipalovammojen ilmaantuvuuden pienentyminen johtuu pääosin vammojen vähenemästä nuorilla.

Suorat hoitokustannukset liekkipalovammapotilaalle olivat 25 400 euroa ja palokaasumyrkytyspotilaalle 3 600 euroa. Näin ollen vuosittainen hoitokustannus liekkivammoille oli 6,2 miljoonaa euroa mistä 5,9 miljoonaa euroa syntyi liekkipalovammoista ja 0,19 miljoonaa euroa palokaasumyrkytysten hoidosta.

Epäsuorat kustannukset menetettynä tuottavuutena olivat noin 28,6 miljoonaa euroa viisivuotisjaksolle 2001-2005 sattuneille tapauksille, joten vuosittainen kustannus oli noin 5,7 miljoonaa euroa ja siten 19 070 euroa per potilas.

Kaiken kaikkiaan noin 43 miljoonaa euroa menetettiin vuodessa liekkivammojen ja palokuolemien seurauksena. Aineettomat kustannukset, joista saattaa seurata merkittäviä summia, jätettiin täysin tutkimuksen ulkopuolelle.

Valtaosa palokuolemista ja vakavimmista liekkivammoista on seurausta asuntopaloista. Näin ollen asuntopalot aiheuttavat suurimmat suorat ja epäsuorat kustannukset sekä terveyden menetysten lisäksi merkittäviä aineellisia vahinkoja ja kustannuksia. Kustannuksia ajatellen, asuntopalot voisivat olla hyödyllisin ehkäisevien toimenpiteiden kohde. Vakavien vammojen ehkäisy iäkkäillä sekä palokuolemien ehkäisy nuorilla tuottaisi suurimmat säästöt. Tulisi pyrkiä kustannustehokkaiden ehkäisykeinojen käyttöön.

SAMMANDRAG

Allvarliga brännskador kan ha svåra följder. Eld och eldsflammor orsakar ofta djupa brännskador och i värsta fall dödliga brandgasförgiftningar.

Undersökningens syfte var att utreda epidemiologin och kostnaderna för flamskador under perioden 2000-2010 i hela landet i Finland.

Undersökningen grundar sig på det nationella vårdanmälningsregistret (HILMO, THL), dödsorsaksstatistik och socioekonomiska bakgrundsuppgifter (Statistikcentralen), brännskadecentrumets urvalsmaterial (Tölö Brännskadecentrum), material om behandlingskostnader (Tölö Brännskadecentrum, Kuopio Brännskadecentrum, övriga Finland) samt material om sociala förmåner i anknytning till hälsa (Keva, FPA). Materialet sammanställdes deterministiskt genom att använda individuella identifierande personuppgifter. Undersökningen är epidemiologisk och beskrivande, i vilken traditionella statistiska metoder (Poissons modell, lineär regression, bootstrap, kvantilregression, generaliserad additiv modell, Wilcoxons test, Kurskal-Wallis test) användes för att beskriva materialet. För beräkningen av indirekta kostnader användes Human Capital –metoden.

Under perioden 2000-2010 inträffade i genomsnitt 99 dödsfall i bränder per år. Majoriteten (76%) av de omkomna var män. Medelåldern för män var 52 år och för kvinnor 57 år. De indirekta kostnaderna för förlorad produktion på grund av dödsfall var i genomsnitt 31,1 miljoner euro per år totalt. Kostnaderna varierade från 800 000 för unga kvinnor till 91 000 för äldre män, när man beaktade de i bränder omkomnas socioekonomiskt genomsnittligt svagare bakgrund. Dessutom förlorades årligen i genomsnitt 2763 potentiella levnadsår som följd av förtida dödsfall. Förlorade levnadsår per dödsfall minskade från 34 (år 2000) till 25 (år 2010).

Årligen inträffade i genomsnitt 300 flamskador som krävde vård på sjukhusavdelning. Majoriteten av de skadade var män (74%). Medelåldern för män var 40,4 år, medan den för kvinnor var 50,4 år. Incidensen av flambrännskador minskade under tioårsperioden 1.1.2000-31.12.2009. Däremot ökade incidensen av brandgasförgiftningar under samma period. Den minskade incidensen av flambrännskador beror huvudsakligen på en minskning bland unga.

Direkta vårdkostnader för en flambrännskadad patient var 24 400 euro och för en brandgasförgiftad patient 3 600 euro. De årliga vårdkostnaderna för flamskador var således 6,2 miljoner euro av vilka 5,9 miljoner euro på grund av flambrännskador och 0,19 miljoner euro för vård av brandgasförgiftningar. De indirekta kostnaderna i form av förlorad produktivitet var cirka 28,6 miljoner euro under femårsperioden 2001-2005 så den årliga kostnaden var cirka 5,7 miljoner euro och 19 070 euro per patient.

Allt som allt förlorades 43 miljoner euro till följd av flamskador och dödsfall i bränder. Immateriella kostnader, som kan uppgå till betydande belopp, lämnades helt utanför undersökningen.

Bostadsbränder orsakade i genomsnitt de allvarligaste skadorna och därigenom de högsta kostnaderna. Majoriteten av dödsfall i bränder beror på bostadsbränder. Dessutom orsakar bostadsbränderna betydande skador på egendom. Med avseende på kostnader är bostadsbränderna det gynnsammaste målet för förebyggande åtgärder. Förebyggande av allvarliga skador bland äldre personer samt förebyggande av fall av branddöd skulle producera den största besparingen. Man bör eftersträva att använda kostnadseffektiva förebyggande metoder.

CONTENTS

A LIST OF ORIGINAL PUBLICATIONS

I. Haikonen K, Lunetta P, Lillsunde PM, Sund R. Methodological challenges in using the Finnish Hospital Discharge Register for studying fire-related injuries leading to inpatient care. *BMC Med Inform Decis Mak*. 2013 Mar 15;13:36.

II. Haikonen K, Lillsunde PM, Lunetta P, Lounamaa A, Vuola J. Fire-related injuries with inpatient care in Finland: a 10-year nationwide study. *Burns* 2013 Jun:39(4):796–802.

III. Haikonen K, Lillsunde PM, Vuola J. Inpatient costs of fire-related injuries in Finland. *Burns* 2014 Dec:40(8):1754–60.

IV. Haikonen K, Lillsunde PM, Lunetta P, Kokki E. Economic burden of fire-related deaths in Finland, 2000–2010: Indirect costs using a human capital approach. *Burns* 2016 Feb:42(1):56–62.

V. Haikonen K, Lillsunde PM. Burden of fire injuries in Finland: Lost productivity and benefits. *J Public Health Res*. 2016 Sep 27;5(2):705.

The articles are referred to in the text by their Roman numerals. Data on outpatient visits in specialised health care due to fire-related injuries reported and discussed here for the first time are referred to as “not published”.

ABBREVIATIONS

ARDS	Acute respiratory distress syndrome
CI	Confidence interval
CO	Carbon monoxide
COHb	Carboxyhemoglobin
DIC	Disseminated intravascular coagulation
E-code	External cause of injury code
ESC	Emergency Services College
FC	Friction cost
FHDR	Finnish Hospital Discharge Register
HCN	Hydrogen cyanide
HC	Human capital
HIC	High income country
ICD	International Classification of Diseases
ICU	Intensive care unit
LMIC	Low- and middle-income country
THL	National Institute for Health and Welfare in Finland
PRONTO	Statistical Data System of Finnish Rescue Services
PYLL	Potential years of life lost
SII	Smoke inhalation injury
SF	Statistics Finland
SPEK	Finnish National Rescue Association
TBSA	Total body surface area
VSL	Value of statistical life

1. INTRODUCTION

A severe burn is a devastating injury that causes considerable morbidity and mortality. In addition to burn injuries, fire-related combustion gas poisonings – often associated with house fires – can be lethal. During the past decade, Finland has been the scene of an excessive number of fire-related deaths in comparison to many other western countries with an average of 90 fatal cases each year and annual rates of up to 20 deaths per million inhabitants. More recent statistics have shown the rate has dropped to 14 per million in 2015, but such a figure is still higher than in many high-income countries (HICs). For example Sweden's, Hungary's and Czech's rate was 11 per million, USA 10 per million and Great Britain's 5 per million(International Association of Fire and Rescue Services 2015).

A Finnish internal safety programme (2008) set the goal of reducing the annual number of deaths to 50 at most in 2015 (Kokki and Jäntti 2009). Unfortunately, this was not achieved since 79 deaths occurred in 2015 (Finnish National Rescue Association). Additionally, hundreds of non-lethal fire-related injuries requiring inpatient care occur annually.

Burn injuries have been studied extensively and several studies have also addressed their associated treatment costs (Hemington-Gorse et al. 2008; Onarheim et al. 2009; Sahin et al. 2011; Ahn and Maitz 2012; Hop et al. 2016; Santos et al. 2016). However, such studies often cover burn injuries in general (i.e. scalds, contact burns) and are not specifically focused on fire-related burns and combustion gas poisonings, which are the two main components of fire-related morbidity and mortality.

In Finland, little scientific knowledge has been gathered on fire-related injuries that includes their costs; there have only been a few, mostly descriptive, studies (Kokki and Jäntti 2009; Kokki 2011).

The purpose of this nationwide register-based study project was to investigate the epidemiology and, in particular, the burden of injuries caused by fire, smoke and flames (fire-related injuries).

2. FIRE-RELATED INJURIES AND THEIR CLINICAL ASPECTS

2.1. FIRE-RELATED INJURIES: GENERAL ASPECTS

2.1.1. OVERVIEW

Fire-related injuries include burns and inhalation injuries, the latter being mainly characterised by local thermal injuries in airways and combustion gas poisoning.

Victims of fire-related incidents may also present a range of other injuries that are not directly connected to thermal exposure and smoke inhalation, such as blunt trauma resulting from falling or jumping from a burning building. In suicides or homicides, victims may also display purposely inflicted wounds that may be a contributing factor to death. However, such injuries represent merely a minor fraction of overall fire-related injuries.

2.1.2. BURNS

2.1.2.1. Definition

Burns are generally defined as a traumatic injury to the skin or other human tissue that is primarily caused by thermal or other acute exposures (electricity, radiation, radioactivity, contact with chemicals, friction) (Evers et al. 2010, Ellison 2013). Thermal agents account for approximately 70% of all burn injuries. Burns are most often accidental, but they may also be self-inflicted or purposely inflicted, for instance, in the context of domestic violence and child abuse (Andreassen and Noyes 1975; Sheth et al. 1994; Cameron et al. 1997; Dorn et al. 2001; Ho et al. 2001; Lalöe 2004; Mannan et al. 2007; Rashid and Gowar 2004; Moniz et al. 2011; Das et al. 2012; Haddadin 2012; Peck 2012).

2.1.2.2. Causes

Burn injuries can be distinguished according to their main causative agent (Di Maio and Di Maio 2001; Hettiaratchy and Dziewulski 2004; Evers et al. 2010; Young et al. 2019). ***Thermal burns*** are caused by (a) flame sources – the most common causes of burns – such as house fires (fire burns) or explosions (flash burns); (b) contact with hot solids (hot steel, cooking pans, hot plates, sauna stoves, pressing iron, lighted cigarettes) (contact burns); or (c) contact with hot liquid, oil and steam (scald burns, further categorised into *spill burns* or *immersion burns*). Thermal injuries also include injuries due to exposure to cold (frostbite). ***Chemical burns*** are generally caused by exposure to strong acids and alkalis (hydrofluoric acid, formic acid, anhydrous ammonia) or other chemicals (white phosphorus, phenol, certain metals). ***Electrical burns*** are caused by the effects of electricity on the body as electrical energy is converted into a thermal injury when the current passes through poorly conducting body tissues.

2.1.2.3. Clinical aspects

Classification (depth and extent). In addition to their causative agents, burns can be classified according to their depth in the skin and subcutaneous tissues, and according to the percentage of the total body surface area (TBSA) involved (Evers et al. 2010; Martin and Falder 2017).

Burn injuries can vary in severity from *mild* to *life threatening*. The depth of the burns depends on several factors (Di Maio and Di Maio 2001; Martin and Falder 2017), including the causative agent and its temperature, the duration of exposure, the thickness of the skin and the areas of the body exposed to the injury, and the type of clothing worn.

Understanding the pathophysiology of burns and their clinical aspects and therapeutic approach requires some basic notions of the anatomy and physiology of skin (Kanitakis 2002; Evers et al. 2020; Martin and Falder 2017; Shpichka et al. 2019).

Basically, the skin consists of three major layers: the epidermis, the dermis (the papillary and reticular dermis, containing connective tissue, blood vessels, nerves, sweat glands, hair follicles) and the hypoderma (subcutaneous adipose and connective tissue). The basal layer of the epidermis supplies new epidermal cells and this explains why superficial, first degree (epidermal) burns heal rapidly without scarring. Similarly, the upper layer of the dermis is more bioactive than the inner one, which explains why superficial second degree (dermal) burns heal faster than deeper dermal burns. Second degree burns heal from the basal cell layer that covers the skin appendages in the dermis (i.e. hair follicles, sweat and sebaceous glands). Dermal burns heal from such appendage-related epidermal stem cells that migrate radially and finally form all layers of normal skin. In deeper wounds, the number of appendages is limited and the healing time will be longer. Prolonged healing over two weeks causes scarring and exposes the skin to infections. This can be avoided by using skin grafts that include the epidermal and superficial part of the dermis, which enables fast closure of the burn wound.

In addition to infection, the loss of normal skin-barrier functions causes some other complications in burns, such as the loss of liquid and increased evaporative water loss (Church et al. 2006).

Traditionally burns have been classified in three to four "degrees", mainly based on the appearance of the skin in the areas affected (Lee et al. 2014). However, recently a more precise classification system has been developed which reflects the depth of the burn and takes into account its healing potential and the need for different therapeutic and surgical approaches (Johnson and Richard 2003; Bishop 2004; Papini 2004; Sicoutris and Holmes 2006; Lee et al. 2014). This classification system distinguishes the following:

(a) ***Superficial burns*** are caused, for instance, by solar radiation or short contact with hot substances. These burns are limited to the epidermis and are characterised by pain, redness, mild swelling and inflammatory response without blisters. They heal within seven days with no permanent skin damage.

(b) ***Superficial partial thickness burns*** involve the epidermis and extend to the uppermost part of the dermis (the papillary region), and are characterised by pain, severe swelling and blisters. They generally heal generally within two to three weeks with no scarring or minor scarring.

(c) ***Deep partial thickness burns*** extend more deeply into the reticular region of the dermis that contains hair follicles, sebaceous and sweat glands, sensory receptors and blood vessels. The skin is white, leathery and relatively painless. These burns generally heal in three to six weeks if no infection occurs and may leave hypertrophic, at time disfiguring and disabling, scars. Surgery with skin grafting is needed to avoid severe scarring and to hasten the healing time.

(d) ***Full thickness burns*** affect all layers of the dermis and eventually the subcutaneous fat and muscle tissue, ligaments and bone. Char and eschar formation is present. These burns always need surgery and tissue grafting.

The assessment of burn depth, which is crucial in planning surgical interventions and fluid resuscitation (Hettiaratchy and Papini 2004), can be challenging. Recently new techniques have been developed to assess the depth of burns more accurately and objectively (using thermal and laser Doppler imaging, and enhanced photographic methods) (Stewart et al. 2005; Tehrani et al. 2008; Hardwicke et al. 2013). Moreover, patients with extensive burn injuries may present burns of different depths and the initial depth of each burn can increase during the first five days. The extent of burns, defined as the percentage of TBSA affected by burns, can be determined by several methods, of which the most commonly used is the “rule of nines”. This method is used for rapid assessment in adults and children over 15–16 years. It excludes epidermal superficial burns and assigns 9% to the head and neck region, 9% to each upper limb (hand, arm, 18% to each lower limb and 18% to each side of the trunk [back, chest and abdomen]). Genitals account for 1% of the body surface area. The Lund and Browder chart provides more accurate estimates and takes into account different body proportions at different ages (Knaysi et al. 1968; Johnson and Richard 2003; Duffy et al. 2006; Sicoutris and Holmes 2006; Granger 2009).

Pathophysiology. Burn injuries cause a local tissue response and a systemic response (Keck et al. 2009; Evers et al. 2010; Nielson 2017).

The local response consists of the formation of three different zones related to tissue damage: an innermost zone of coagulation, a central zone of stasis and an outermost zone of hyperemia. The coagulation zone corresponds to the area where the causative agents have caused most of the damage, with no blood flow and with irreversible damage to injured cells (Jackson 1953). The coagulation zone is surrounded by the zone of stasis, characterised by capillary vasoconstriction, decreased tissue perfusion and ischemic changes. In this zone the cellular damage is potentially reversible with appropriate fluid therapy, but prolonged hypotension, infection or oedema can result in an area necrosis. The outermost hyperemic zone has significantly less cellular damage and is characterised by increased blood circulation that is necessary to transport nutrients for tissue recovery and for removing waste products; in this area, the damaged tissues will completely recover unless sepsis or prolonged hypoperfusion occur (Hettiaratchy and Dziewulski 2004; Evers et al. 2010; Hussain and Dunn 2013).

A patient with burns covering 20% or more of his or her TBSA usually present a large ***systemic reaction*** (Hettiaratchy and Dziewulski 2004; Keck et al. 2009). The pathophysiology and cellular mechanisms of this systemic response are complex and, in many aspects, still poorly understood (Nielson et al. 2017). The release of cytokines and several other local and inflammatory mediators and stress hormones from the burned area causes systemic changes affecting the following:

(a) ***The cardiovascular system*** is affected with an increase in the capillary permeability, the passage of protein and liquid into the interstitial compartment, peripheral and organ vasoconstriction, a decrease in myocardial contractility and liquid loss by evaporation, all of which may result in systemic hypotension and organs’ hypoperfusion with tissue ischemia and acidosis (burn shock) (Hettiaratchy and Dziewulski 2004; Keck et al. 2009). Electrolyte imbalance includes the loss of sodium, chloride, phosphate and calcium (Aulick et al. 1977; Demling et al. 1978; Hilton and Marullo 1986).

(b) ***The respiratory system*** is affected with bronchoconstriction and, in severe burns, adult respiratory distress syndrome (ARDS) which is usually caused by the toxic elements of burned materials or as a complication of fluid resuscitation or sepsis (Hettiaratchy and Dziewulski 2004).

(c) ***Metabolic*** changes start around five days post injury, especially in burns covering more than 40% TBSA, and can at times persist several months. They are driven by the release of cortisol and catecholamines and are characterised by a marked increase in the basal metabolic rates, the cardiac output and the heart rate. This hypermetabolic response is characterised by increased body temperature, glucose consumption, glycogenolysis, proteolysis and lipolysis and is associated with impaired wound healing, risk of infections and the loss of body mass . When the hypermetabolic phase alleviates, a longstanding abnormal metabolic state may continue for even longer than one year after the initial burns (Herndon et al. 2004; Porter et al. 2016, Williams and Herndon 2017; Stanojcic et al. 2018).

(d) ***The immune system*** is affected, resulting in an increased risk of infection and sepsis (Church et al. 2006).

Complications. Depending on the burn depth, extension and location, burn injury patients may experience a wide range of severe and potentially fatal immediate or late complications.

Infections account for up to 75–80% of overall mortality in burn injuries (Bang et al. 2002; Church et al. 2006; Sharma 2007). The disruption of the skin due to a burn injury allows environmental micro-organisms and endogenous microbes located in the skin and its appendages to colonise deep tissues. Several endogenous and exogenous micro-organisms are associated with burn wound infection. Staphylococcus aureus and Pseudomonas aeruginosa are among the most frequently found micro-organisms isolated from burn injuries (Church et al. 2006). In addition to local burn wound infections, other infective complications include sepsis, pneumonia, infection of the urinary tract and cellulitis (Church et al. 2006).

Burn-associated hypovolaemia with haemoconcentration occurs, usually in the first 24 hours post injury, as a consequence of damage to small blood vessels, resulting in the local exudation of proteins into the interstitial space at the site of burns or, in larger burns, diffusely in the body (Hettiaratchy and Dziewulski 2004; Keck et al. 2009). The subsequent hypovolemic state can lead to acute renal failure and deterioration of blood circulation in the gastroenteric system, at times with a fatal outcome.

Other severe complications include ARDS, disseminated intravascular coagulation (DIC) (Herndon 2007; Lippi et al. 2010) and acute compartment syndrome (circumferential burns lead to increased pressure in tissues of the torso and extremities, hampering ventilation and blood perfusion) (Butts et al. 2019). Another mechanism of death in burn patients, although more rare, is pulmonary embolism due to the patient's prolonged immobilisation and circulatory changes related to the burn injury and its treatment (Kallinen et al. 2012).

The long-term consequences of non-fatal burns are both psychological and physical, and may include post-traumatic stress, depression and anxiety, loss of social network and phobias (also related to long term hospitalisation), as well as hypertrophic scarring and keloid formations with contractures, deformities and disfiguration (Van Loey and Van Son 2003; Palmu 2004).

Management/treatment. The management and treatment of burns, the detailed description of which goes beyond the purpose of the present study, varies according to their severity and extension (Hettiaratchy and Papini 2004a, 2004b; Hudspith and Rayatt 2004; Ansermino and Hemsley 2004; Papini 2004; Wiechman and Patterson 2004; Sicoutris and Holmes 2006; Alharbi et al. 2012; Lee et al. 2014). Overall burn treatment aims to provide first aid, pre-hospital care, transportation to an appropriate medical facility, management of the emergency period (resuscitation), renewal of damaged and destroyed skin in acute periods, prevention and treatment of all complications, main surgical reconstruction, and somatic and psychosocial rehabilitation (European Burns Association 2017).

The treatment of minor burns suitable for outpatient management include (a) initial rescue and first aid (removal of the patient from the source of burns, cooling the burn with lukewarm water, analgesic treatment, covering the burns and warming the patient) and (b) cleaning and dressing the burn wound (Hudspith and Rayatt 2004). The management of a major burn essentially includes the following actions (Hettiaratchy and Papini 2004a, 2004b; Papini 2004; Alharbi et al. 2012): (a) primary survey and emergency management (assessment of the airways; breathing, circulation, and neurological status; patient covering and warming; analgesic treatment); (b) secondary survey for any concomitant injuries; (c) cleaning and dressing the burn wound; (d) assessment of the burn area and depth, fluid resuscitation; (e) referral to a burns unit; (f) escharotomies (the division of the circumferential burn eschar to release the tissue pressure and allow peripheral circulation and chest excursions); (g) surgery with wound excision and grafting; (h) the prevention and treatment of wound infection, sepsis, and other complications; (i) supportive treatment for the acute and log-term psychophysical consequences of severe burns.

2.1.3. SMOKE INHALATION INJURIES: AIRWAYS' THERMAL INJURIES AND COMBUSTION GAS POISONINGS

2.1.3.1. Overview

Smoke inhalation injuries (SIIs) occur during enclosed-space fires and consist of local thermal injuries to the airways and the local and systemic effects of toxic chemical irritants and particulate matters originating from smoke – products of incomplete combustion. These agents may schematically cause (a) upper airways injuries by thermal damage and chemical irritation with erythema, oedema, haemorrhages and ulceration; (b) upper and lower airway and lung injury caused by chemical irritation and particulate matter from smoke; and (c) systemic toxicity by carbon monoxide (CO) and hydrogen cyanide (HCN) poisoning. These damages result in symptoms of acute respiratory failure and hypoxia. SIIs are often associated with severe burns and it is estimated that 60–80% of all sudden deaths occurring in enclosed-space fires are attributable to SIIs (Alarie 2002; Enkhbaatar and Traber 2004; Cancio 2005; Lee and Mellins 2006; Micak et al. 2007; Cancio 2009; Woodson 2009; Antonio et al. 2013; Yeung et al. 2013; Huzar et al. 2013; Megarbane and Lefort 2013).

2.1.3.2. Causes of combustion gas poisoning (by CO, HCN)

CO is a colourless, odourless, tasteless and non-irritant gas that is absorbed through the lungs, and it results from the incomplete combustion of hydrocarbons, especially in poorly functioning heating systems and in environments with inadequate ventilation for flame-based heating sources (Weaver 1999; Prockop and Chichkova 2007). Several other sources of CO exposure, such as motor vehicle exhaust and fuel-powered generators, have been recognized (Abelsohn et al. 2002), but their description goes beyond the aims of the present study.

HCN is a highly volatile chemical compound formed during a fire by the incomplete combustion of several materials, such as natural polymers (silk) or synthetic polymers (plastics, acrylics), that contain nitrogen or halogens (Alarie 2002; Hamel 2011; Anseeuw 2013; Antonio et al. 2013; Megarbane and Lefort 2013; Dinh and Rosini 2014). Smoke inhalation during an enclosed-space fire is one of the several sources of cyanide intoxication. Otherwise, cyanide exists in the form of gas, liquid and salt; it is a rapidly acting and deadly poison, the symptoms of which can appear within seconds to minutes, depending on the route and duration of exposure.

2.1.3.3. Clinical aspects

Pathophysiology. In normal conditions, oxygen diffuses across the lung's alveolo-capillary membrane and binds with haemoglobin in blood. Increased CO concentration in the air interferes with normal oxygen transport to tissues. Indeed, CO binds rapidly to haemoglobin and, with an affinity approximately 210–240 times greater than oxygen, forms carboxyhaemoglobin (COHb). Due to changes in the haemoglobin structure, COHb cannot transport and release as much oxygen to tissue as haemoglobin usually does, and this reduced capacity results in tissue hypoxia. The heart and brain, highly metabolic organs, are primarily affected. In the heart, for instance, CO binds to myoglobin approximately 60 times faster than oxygen, causing myocardial ischemia, also when there is no coronary artery disease. CO has also a direct toxic effect on tissues (Prockop and Chichkova 2007; Betterman and Patel 2014; Wu and Juurlink 2014).

In cyanide toxicity, the oxygen supply to body tissue is adequate but the extraction of oxygen to cells is impaired due to the binding of cyanide tissue enzymes (e.g. cytochrome c oxidase) that prevent mytocondrial respiration at cellular level and ultimately results in cell deaths (Morocco 2005; Nelson 2006; Borron 2006; Hamel 2011; Dinh and Rosini 2014).

Signs and symptoms. CO can cause acute or chronic poisoning depending on its concentrations in the inhaled air, the exposure time, the alveolar ventilation rate and the presence of comorbidities (Kealey 2009; Antonio et al. 2013). The effects of CO intoxication range from minor cardiovascular and neurobehavioral effects at low concentration to unconsciousness and death from prolonged and acute exposure to high concentrations. Several studies have addressed the symptoms associated with different COHb levels, but the correlation between symptoms, signs and prognosis and COHb levels is somehow unpredictable (Norkool 1985; Raub et al. 2000). In a healthy individual, the average COHb level is 1–2%, but in habitual smokers this level can be as high as 10–15%. The clinical presentation of CO toxicity for values below 20% is inconsistent although reduced performance (visual perception, motor coordination and complex tasks of judgment) and symptoms, such as fatigue and headaches, have been reported (Peter and Juurlink 2014; Betterman and Patel 2014; Bleecker 2015). Schematically, the onset of symptoms is usually observed at COHb concentrations above 20%, and these include headaches, weakness, dizziness, nausea, vomiting, confusion, visual disturbances and memory problems, as well as seizures (Raub et al. 2000). Loss of consciousness and comas generally occur with a COHb level of 30–50%. Death does not generally occur at COHb levels <40%, but fatal incidents may occur in less than two hours when the COHb level is as low as 40%. At the COHb level of 50%, headaches, dizziness and nausea appear within 5–10 minutes and death within 30 minutes; at the COHb level of 60%, headaches and dizziness appear in one to two minutes, seizures, comas and cardiorespiratory arrest and death in less than 20 minutes; at COHb levels >70%, death intervenes in less than three minutes. Individuals suffering from chronic lung and heart conditions have low tolerance to hypoxia and may present symptoms and signs at lower COHb concentrations and with lower exposure times compared to healthy individuals.

In cyanide poisoning, early signs and symptoms include headaches, confusion tachypnoea and tachycardia whereas more advanced consequences include an altered level of consciousness, seizures, comas, hypoventilation, hypotension and death.

Complications. Late complications of non-fatal CO poisoning consist of a delayed neuropsychiatric syndrome that may occur in 10–30% of the cases, with an interval ranging from a few days to several weeks after exposure. CO poisoning may cause diffuse demyelination in the nervous system with – in the case of the involvement of the globus pallidus – Parkinsonisms and neuropsychological effects, for example personality changes, and cognitive impairment, such as impaired judgment, poor concentration, memory loss and neurological deficits, dementia and psychosis (Tibles and Perrotta 1994; Ernst and Zibrak 1998; Mimura et al 1999; Varon et al. 1999; Choi 2002; Kao and Nanagas 2004; Bhatia et al. 2007; Lin et al. 2009). Cardiac arrhythmias and myocardial infarction with no coronary disease – as well as pulmonary oedema, skeletal muscle necrosis, renal failure and hepatocellular injuries – have also been described as complications of CO poisoning (Marius-Nunez 1990; Raub et al. 2000; Prockop and Chichkova 2007).

Management/treatment. The treatment of smoke inhalation injuries is mainly supportive, involving immediate O_2 therapy and protective mechanical ventilation (Raub 2000; Prockop 2007; Antonio 2013). In the case where inhalation injuries are present or suspected, early intubation may be appropriate. Fibre-optic bronchoscopy is recommended for diagnosing an acute inhalation injury and intubation in patients with signs of an upper airway injury or unconsciousness.

The management of CO poisoning is based on removing the victims from the exposure source and supplying pure oxygen to eliminate CO and improve tissue oxygenation. Patients with mild CO poisoning respond to treatment with 100% oxygen at normal barometric pressure (NBo_2) whereas in more severe CO poisoning cases, hyperbaric oxygen (HBo_2) is the treatment of choice when available. However the precise conditions requiring NBo_2 or HBo_2 therapy and their outcomes is controversial (Juulink et al. 2000; Raub 2000; Stoller 2007; Buckley et al. 2011; Bebarta et al. 2012; Thompson and Marrs 2012; Dinh et al. 2014).

The treatment of cyanide toxicity consists of removal from the source of exposure, supportive care with basic or advanced life support, eventually administration of

100% oxygen and the use of antidotal therapy (for instance, in combined CO and cyanide toxicity, hydroxocobalamin and sodium thiosulfate) (Morocco 2005; Borron 2006; Hall et al. 2007; Shepherd and Velez 2008; Thompson and Marrs 2012; Bebarta 2012; Wu and Juurlink 2014; Dinh et al. 2014).

3. THE EPIDEMIOLOGY OF FIRE-RELATED INJURIES

3.1. EPIDEMIOLOGY OF BURNS

3.1.1. FATAL BURNS

There are studies concerning fire fatalities. However, the wide variety of settings – mostly local or regional – together with the different study periods considered and age groups selected, as well as the victims' heterogeneous clinical factors (e.g. TBSA), significantly hinders the comparison of data.

In the US, Istre et al. (2002) investigated residential fire-related deaths and injuries among 0–19-years-olds in Dallas (Texas) during 1991–1998, with the corresponding census covering some 280,000 people. This study revealed that 39 children had died due to residential fires. Playing with fire, usually with matches or lighters, accounted for 42% of all such injuries. The study also revealed that smoke alarms were ineffective at preventing deaths or injuries due to fireplay or arson, but were effective in other cases. In another study, Istre et al. (2001) investigated house fires that had occurred during 1991–1997 in Dallas, with all ages of victims being covered. They found that a total of 7,190 house fires occurred during the survey period, causing 223 injuries (91 fatal injuries, 132 non-fatal injuries). Males and the elderly were at greater risk. They also observed that low-income areas had much higher injury rates than high-income areas. In relation to these findings, , also observed in the US by Perry et al. (2015) a lower prevalence of functioning smoke detectors in low-income areas was detected.

In England, Mulvaney et al. (2009) studied deaths caused by fires over a 10-year period, 1995–2004. A total of 75% of the fatal injuries occurred in dwelling fires. A significant reduction in fatal injury rates was observed in all age groups during the study period. They observed a 30% reduction among adolescents, 33% among adults and 24% among the elderly. The primary causes of fatal fires in adults were smokers' materials. Matches and lighters were a common cause among children. Most cases occurred among the most socio-economically disadvantaged groups. A reason behind reduction in accidents involving smokers' materials was suggested to be reduction in the prevalence of smoking.

Generally, those socio-economically less fortunate are at greater risk of death due to fire. Peck and Pressman (2013) compared the relationship between fire-related deaths and various economic indicators at national level in 189 countries; they observed significant correlations between the number of fire-related deaths and 1) gross domestic product, 2) the gross national index and 3) the Gini coefficient (a measure of the inequality of distribution of wealth). In general, it was concluded that fire-related deaths are more frequent, the poorer or more deprived the country tends to be.

Fire-related inhalation injuries lead to high rates of morbidity and mortality. According to Wise and Levine (2015), inhalation injuries, especially in cases of facial burns, lead to respiratory failure in 70% of patients while proving fatal in 30% of cases. In addition to airways injuries, there is a risk of hypoxemia due to CO and HCN inhalation, particularly if the fire occurs in an enclosed space. Inhalation injury increases the incidence of pneumonia, respiratory failure and sepsis (Chen et al. 2014) and is an important prognostic factor. El Helbawy and Ghareeb (2011) compared burn patients with inhalation injuries to those without. The difference in mortality rates was significant; mortality among those with inhalation injuries was 41.5%, but only 7.2% among those without such injuries. The Baux score has been used to measure the severity of a burn injury by summing patient's age and the extent of the burn (TBSA). An inhalation injury has been proposed to update the Baux score with an addition of 17 points in the case of an inhalation injury occurs, which means it has a similar impact to an additional age of 17 years or an additional burn extent of 17% (Davis et al. 2013).

Aside from deaths at the scene of the accident or pre-hospital deaths, burn injuries are responsible for a significant amount of in-hospital mortality as well. A wide range of in-hospital mortality rates have been reported in medical literature. A study from the Netherlands reported the in-hospital mortality rate for burn injuries to be 3.2% while the mean TBSA for all patients was 8% (Dokter et al. 2015). Another Dutch study compared data from the Rotterdam Burn Centre in the Netherlands (RBC) with those from the American National Burn Repository (NBR); mortality rates were 6.9% and 5.6% respectively (Bloemsma et al. 2008). A large population-based study from England based on 188,597 burn injury hospital admissions revealed an in-hospital mortality rate of 1.7% (Brewster et al. 2013). In Portugal, Santos et al. (2016) reported in-hospital mortality at 4.4% with mean TBSA for the deceased at 37% and 10% for those who survived. Brusselaers et al. (2010) conducted a systematic review of studies on severe burns in Europe. As the studies included in this review covered very heterogeneous settings in terms of countries and selected patients, the mortality rates were very dissimilar, ranging from 1.4% to 34%. A major factor affecting mortality rates is TBSA. In a UK burn centre in Liverpool, Jeevan et al. (2014) assessed lethal area 50 (which is defined as the burn size that is lethal to 50% of patients). They found it to be 71.1%, 56.6% and 28.8% for the age groups 15–44, 45–64, and 65 and over respectively.

Additionally, a variety of mortality studies have been performed in low- and middle-income countries (LMICs). In Iran, among 13,248 patients admitted in a burn centre in Kermanshah, overall mortality was 1.6% while median TBSA was some 4% (Ahmadijouybari et al. 2014). In Turkey, a 4.6% mortality rate was observed among 3010 burn patients (Tekin et al. 2013). In an Iraqi burn centre, the mortality was as high as 29% with three quarters of the deceased patients having TBSA of 50% or greater (Qader 2012). Belba and Petrela (2012) investigated the mortality of burn patients in a burn centre in Albania: they estimated overall mortality was 10.5% while the mean TBSA of all patients was 22.8%. In Sri Lanka, a mortality rate of 27% was reported with median TBSA for all patients of 16% (Laloe 2002).

In Finland, Kokki and Jäntti (2009) studied fire-related deaths during 2007 and 2008. A total of 85 deaths occurred in 2007 and 107 in 2008. Most of these deaths (91%) were due to building fires. The average age of the victims was 57 and the greatest risk of death was observed in the 60–69 years old age group. Most fire-related deaths occurred during the cold season: nearly half of all victims died from December to March.

Aside from a burn being unintentional, it can be also be self-inflicted or deliberately inflicted by others. A variety of mortality rates due to self-inflicted burns (the proportion of fatal cases among all self-inflicted cases) has been reported. An Irish study reported a rate of 7.9% (Seoighe et al. 2011) while in a UK study it was 13.5% (Caine et al. 2016) and in Finland at the Helsinki Burn Centre it was 17.4% (Palmu et al. 2004). In another UK study by Malic et al. (2007) it was as high as 29.1%. Among self-inflicted burns, by flame is the most frequent manner in which the burn was inflicted, accounting for 76–88% of the cases in these studies. In Hong Kong, 39% of 31 suicidal burns during 2000–2009 were due to flames (Chan and Burd 2012).

3.1.2. NON-FATAL BURNS

Several research studies have been conducted in many countries on non-fatal burn injuries, including those that are fire-related. In Finland, only few studies have addressed non-fatal fire-related injuries.

A Scottish study (Sarhadi et al. 2001) examined patients treated in the Glasgow Burns Unit during the period 1981–1993. A total of 1,181 patients with fire-related injuries were treated, which was 43% of all burn patients admitted. Admission for flame burns showed a decreasing trend in all age groups. Decreasing trends in fire injuries were also observed in England (Mulvaney et al. 2009) during the period 1995–2004: a 30% decline was reported among adolescents, 33% among adults and 24% among the elderly. In this study, cooking appliances were the main causes of fire injuries.

In the USA, Kraft et al. (2011)(is there a difference clinical outcome) studied burns among children by comparing the differences between liquid- and fire-related injuries in terms of treatment challenges and complications. They observed that patients with fire-related injuries more often presented withhypermetabolic inflammatory disorders. In addition, cases of sepsis were almost five times more common among patients with fire-related injuries than those with liquid burns. In another US study, Neaman et al. (2010) studied burn injuries due to recreational outdoor fires. They recorded a total of 329 patients over an eight-year period: 2001–2009. Of these, 118 required inpatient care. Most of the injuries were due to campfires (81.8% in adults, 93.9% in paediatric patients). Using an accelerant (such as gasoline) for a campfire was a common cause of burn injuries among adults. In children, accidental falls into active fires and/or walking on burned ashes were the most common causes of injury.

In Finland, a study of the first 1,000 burn patients admitted to the Kuopio Burns Unit (Papp 2009) revealed that fire-related injuries accounted for 31.1% of all burns, but the proportion rose to 73.1% among cases requiring intensive care, reflecting the more severe nature of fire-related injuries compared to other kinds of burns. However, the proportion of fire-related injuries among 0–16- year-olds treated in the intensive care unit was only 36% (Papp et al. 2008). This reflects the lower incidence of fire-related burns among children and adolescents.

Kokki and Jäntti (2009) have investigated severe fire injuries in Finland. An injury was defined as *severe* if it required over two days of inpatient treatment and involved a bone fracture; continuous bleeding; nerve, muscle or tendon injuries; internal organ damage; second or third-degree burns; a burn extending over more than five percent of the skin; an infection; or an injury caused by radiation or exposure to corrosive or toxic substances. During 2007–2008, the authors observed that out of 131 patients with such injuries, 105 were still alive after 30 days. The severely injured patients tended to be a little younger (50 versus 56 years old) than the victims of fire-related deaths in general. The incidence was somewhat lower in the cold season compared with fire-related deaths, with severe injuries being more evenly distributed throughout the year than fatalities.

Some studies have also assessed self-inflicted non-fatal burn injuries. In the UK, Malic et al. (2007) reported that out of 1745 burn patients, 86 (4.9%) had self-inflicted burns. An Irish study identified 4.2% of total burn admissions being related to self-harm (Seoighe et al. 2011). In England, Caine et al. (2016) studied 118 patients with self-inflicted burns admitted to a burn unit during 2005–2014 and found that flames accounted for three quarter of the cases. In Finland, Palmu et al. (2004) investigated burn patients admitted to a Helsinki Burn Centre during

1989–1997 and found that out of 811 patients, 5.7% had attempted suicide, exposure to flame being the most recurrent (82.1%) method.

3.2. EPIDEMIOLOGY OF COMBUSTION GAS POISONINGS

3.2.1. FATAL COMBUSTION GAS POISONINGS

Inhalation of combustion gases, especially CO and HCN, plays an important role in fire-related deaths. According to some estimates, as many as 60 to 80% of fire-related deaths are due combustion gases rather than burn injuries alone (Barillo et al. 1986; Lundquist et al. 1989; Banfield et al. 2015; Stevens et al. 2015). In Sweden, Jonsson et al. (2016) noted that while in the 1970s burns were the primary cause of death, nowadays CO poisoning accounts for the majority of fire-related deaths. Swedish forensic toxicological data from 1992–2009 (n = 2303) was assessed for fire victims and also for HCN blood concentrations. Among them, 17% had lethal or life-threatening blood cyanide levels and 31% had had significant HCN exposure (Stamyr et al. 2012). In Poland, Grabowska et al. (2012) found, in a series of 285 fire-related deaths, a positive post-mortem result for HCN in 59% of the victims. Yeoh and Braitberg (2004) investigated CO and HCN poisonings in fire-related deaths in Victoria, Australia. They observed that 82% of the victims died at the scene of the accident and the remainder after a period of hospitalisation. It was also found that the blood alcohol level significantly correlated with carboxyhaemoglobin and cyanide levels. Cone et al. (2008) concluded that “Carbon monoxide poses a greater threat to victims and firefighters than does oxygen deprivation or heat”.

In the Czech Republic, Janik et al. (2017) observed that unintentional fire-related fatal CO poisonings represent as much as 21% of all CO poisonings. In this study, the mean victims’ age was 48 years old and the majority of victims were males (59%). Conversely, in China, Li et al. (2015) reported that fire is the cause of approximately 61% of overall unintentional CO poisonings. In a US study, Cook et al. (1995) estimated fire-related poisoning to be 36.2% of all CO intoxications.

Data on fire-related CO poisoning in suicides are lacking, although non-fire–related CO poisonings remain a relatively common method of suicide in many countries (Schmitt et al. 2011; Nielsen et al. 2014; Hampson 2016). For example, in Taiwan, suicide by CO poisoning due to burning charcoal accounted for a one third of all suicides in 2006 (Pan et al. 2010). Correspondingly, in South Korea, 7.9% of suicides were due to CO poisoning of any source in 2012 (Choi et al. 2014) and nearly 12% in the elderly population in Australia (Byard et al. 2004) due to car exhaust. However, a significant decline in intentional CO poisoning has been recently reported in countries such as the US, England and Wales, and Japan where there has been reduction in availability of CO for domestic use especially due to reduction of CO in car exhaust (Gunnell et al. 2015; Hampson 2016; Yoshioka et al. 2018).

3.2.2. NON-FATAL COMBUSTION GAS POISONINGS

Studies on non-fatal fire-related CO or combustion gas poisonings are scarce. Most studies address non-fire-related CO poisonings. For example, in the US, Harduar-Morano and Watkins (2011) investigated unintentional non-fire–related CO poisonings 1999–2007 and observed that the majority of poisonings were due to motor vehicle exhaust and generators. Another US study from 1986–1991 observed a considerably lower estimate of fire prevalence with only 6.6% out of 807 CO poisonings being related to fire (Cook et al. 1995).

In Israel, Salameh et al. (2009) reported that patients treated for fire-related CO poisoning represented approximately one third of all patients treated for CO poisoning, the majority of which were heater related. Duenas-Laita et al. (2001) examined acute CO poisoning in a Spanish region. Among 154 patients, mean age was 32.2 years old and 69% were females. In this study, the majority (53%) of poisonings was related to water heaters and only 12% were fire related. In Lebanon, El Sayed and Tamim (2014) surveyed emergency department visits due to CO poisoning and found that 37% were fire related. In the latter cases, nine out of ten patients were males and the mean age was 33 years old. The study only included patients for whom the CoHb level in their blood was available; this limited the study to 32 patients in a four-year period.

3.3. THE FINNISH SOURCE OF FATAL AND NON-FATAL EPIDEMIOLOGICAL DATA

3.3.1. CAUSE-OF-DEATH STATISTICS

Statistical data on causes of death are produced annually by Statistics Finland (SF) and belongs to the Official Statistics of Finland (Statistics Finland 2017). SF data include all deaths in Finland or abroad of persons permanently resident in Finland at the time of their deaths.

Statistics on the cause of death are compiled on the basis of death certificates, issued by the physician establishing the death. The physician records the cause of death on the death certificate as a code and as a text specifying the diagnosis. If determining the cause of death requires a medico-legal autopsy, the death certificate is issued by a forensic pathologist after the information acquired from the autopsy is complete (Statistics Finland 2017).

The physician issuing the death certificate delivers the certificate to the regional unit of the National Institute for Health and Welfare in Finland (THL) in which the deceased was a resident and reports the death to the Population Information System. In this way, the coverage of the cause of death statistics is around 100 per cent because the data on death are verified from the Population Information System.

At the THL, a forensic pathologist verifies the correctness of the certificate before it is sent on to SF. At SF, the death certificate data are compared with data on the deceased obtained from the Population Information System and diagnosis texts and cause of death codes issued by physicians are checked with the help of an electronic dictionary. In case the information on the death certificate is deficient, inconsistent or difficult to classify, the information about the event recorded on the death certificate or a medical expert will be consulted or more information will be requested from the issuer of the death certificate. Data files on causes of death are supplemented with other demographic data from the Population Information System (Statistics Finland 2017).

According to Finnish law (Act 459/1973), a medico-legal investigation into the cause of death must be performed when death is caused (or is suspected to be caused) by crime, accident, suicide, poisoning, occupational disease or medical treatment; when death has not been caused by a disease;, when, during the last illness, the deceased had not been treated by a doctor; and when death is otherwise unexpected. The consent of the victim's next of kin for medicolegal autopsy is not required (Lunetta et al. 2007).

Statistics on causes of death are used for scientific research purposes in a range of studies focusing on injuries or diseases. For example, using cause of death data provided by SF, Lunetta et al. (2004) have investigated unintentional drowning in Finland from 1970 to 2000, Panula et al. (2011) investigated the mortality of hip fracture patients, Parkkari et al. (2013) investigated fatal childhood injuries during 1971–2010 and Raatiniemi et al. (2016) surveyed fatal injuries in northern Finland. Additionally, there are studies investigating the validity or quality of the cause-of-death statistics although not specifically about injuries (Leppälä et al. 1999; Lahti 2005; Tolonen et al. 2007).

3.3.2. THE FINNISH HOSPITAL DISCHARGE REGISTER

The Finnish Hospital Discharge Register (FHDR) (THL 2019b) has been frequently used for research purposes. The data has been used to study various topics, to name a few: amputations among diabetics (Winell et al. 2006), suicides following discharge from psychiatric care (Pirkola et al. 2005), surgical treatment of clavicular fractures (Huttunen at al. 2013), trends in myocardial infarction (Mähönen et al. 1995), the length of hospital stay for chronic obstructive pulmonary disease (Kinnunen et al. 2002), the mortality of schizophrenic patients (Rantanen et al. 2009), the incidence of fall-induced severe head injuries (Kannus et al. 1999) and ankle fractures in the elderly (Kannus et al. 2002). Kouvonen et al. (2014) assessed national trends in the main causes of hospitalisation during 1976–2010 using the FHDR. The FHDR has also been used in some burn studies. Laitakari et al. (2015) studied the incidence and risk factors of burn injuries among infants while the risk for end-stage renal disease after burns was studied by Helanterä et al. (2016).

The quality of the FHDR has been assessed in different studies targeting injuries and diseases. Lunetta et al. (2008) assessed the underreporting of external cause-of-injury codes (E-codes) in the register during 1987–2004. Underreporting was marked after the introduction of the ICD-10 (1996) classification in Finland. During the first years following the introduction of ICD-10, the proportion of missing E-codes was as high as 57.5% among all injury admissions. Underreporting diminished to 12.8% during 2002–2004. The coverage and accuracy of cruciate ligament injury diagnoses in the FHDR was analyzed by Mattila et al. (2008). They found coverage to be 92% and accuracy to be 89%. Sund (2012) conducted a systematic review on the quality of the FHDR consisting of 32 different studies. Most of the studies concerned vascular diseases but six were on injuries. This author estimated that completeness and accuracy of the FHDR varies from *satisfactory* to *very good*. Among injuries, the coverage ranged from 90% to 98% and the positive predictive value (Altman and Bland 1994) ranged from 89% to 98%.

3.4. RISK FACTORS OF FIRE INJURIES AND DEATHS

3.4.1. CIRCUMSTANTIAL RISK FACTORS

Several circumstantial risk factors may increase the risk of house and non-residential fire-related death or injury. These factors range from faulty heating equipment, the proximity of ignitable substances to a source of heat and malfunctioning or a lack of smoke detectors through to insufficient parental or professional supervision and the occurrence of fire in isolated areas or during the night or weekend, all of which hamper potential rescuers from promptly intervening at the sites (Turner et al. 2017).

Absence or malfunction of smoke alarm is a major risk factor for injury sustained from a fire as it hinders the ability to notice a fire once it occurs and is still in a developing stage. Therefore, it is a direct risk factor. A Canadian study assessed paediatric fire deaths from 2001 through to 2006 (Chen et al. 2011). The authors observed that a smoke alarm was present in 82% of the cases but only 54% were functioning. In Texas, a US community-based smoke alarm programme was implemented with the installation of 8134 smoke alarms in houses. The mean follow-up time was 5.2 years. At that time fire-related deaths and injuries were 68% lower among those participating in the programme versus those that did not participate in it (Istre et al. 2014). A challenge with smoke alarms is that they may become malfunctioning or even be removed over time. McCoy et al. (2014) observed that in a sample of 800 houses, merely a quarter of smoke alarms were present and functioning 10 years after installation. A US study conducted in the 1990s reported that the presence of smoke alarms was more common in urban settings (41.8%) than rural settings (20.8%) (McGwin et al. 2000). Another recent US survey study on fire safety issues demonstrated that among 1003 responders, some 97% had at least one smoke alarm in the household (Runyan et al. 2005). These studies suggest that the prevalence of smoke alarms may be high in general, but they do not assess how common the presence of smoke alarms is in cases where injury or death occurs.

There is some evidence of the type of residence being a risk factor for fire. In a US study, Allareddy et al. (2007) estimated the risk of fire to be greater in rural households than in towns (OR = 1.85). On the other hand, Jonsson et al. (2017) stated that fatal fires occur roughly as often in houses as in apartments in Sweden. Interestingly, another US study by Shai (2006) found that the combined effect of older housing and low income yielded elevated fire injury rates. Some evidence exists too of the increased use of interior materials producing toxic combustion gas in homes (Kaita et al. 2018) which is a risk factor of injury once a fire occurs.

In Finland, in most cases, the materials that ignited first were furniture and interior decor (among deaths 33%, among severe injuries 34%) and clothing and textiles (15,24%). The reason of ignition in each material was not reported. No smoke alarm was present in 53% of cases involving serious injuries (Kokki 2009).

3.4.2. INDIVIDUAL RISK FACTORS

3.4.2.1 Smoking as a risk factor

In Finland, a two-year survey performed in 2007 and 2008 disclosed that smoking was the most common cause of fire (Kokki 2009). In Sweden, some 27% to one third of fatal residential fires were smoking related (Bonander et al. 2016; Jonsson et al. 2017). In a Scottish study (Sarhadi et al. 2001), smoking was associated with a half of the patients with fire-related burns. A UK study disclosed that adult fire deaths were most commonly caused by smokers' materials (Mulvaney et al. 2009).

Runyan et al. (1992) reported in their US case-control study that fatal fires were more likely to be caused by smoking than non-fatal fires (31% vs 6%). In another US study, Diekman et al. (2008) observed that state-level prevalence of adults smoking correlates with the rates of residential fires and that a 1% decrease in the percentage of smokers resulted in a 7% decrease in the modelled residential fire rate.

Turner et al. (2017) conducted a systematic review of risk factors associated with unintentional house fires in HICs consisting of 11 eligible studies. They found that smoking was clearly associated with these incidents; household whose residents smoked 10–19 cigarettes per day had six times greater odds of injury/fatality than those with no smokers. In Australia, Xiong et al. (2015) compared fatal accidents to those with survival and found a significantly higher proportion of smoking materials to be the igniting factor in fatal fires (45.1% vs 2.9%).

3.4.2.2. Alcohol as a risk factor

Alcohol consumption is a major contributing risk factor in fire-related deaths. It may directly contribute to a risk of injury and indirectly by a way of increasing a risk of fire per se. A Norwegian study (Rodge and Olving 1996) based on 286 fire-related deaths found BAC exceeding 0.1 mg/ml among 46% of the victims and suggested that alcohol impairs the victim's ability to escape. In Sweden, Sjögren et al. (2000) surveyed the relationship between alcohol and unnatural deaths. They found 36.3% of the cases exceeded BAC 0.02%. Among unintentional fire deaths the figure was 47.6%. The mean BAC for fire victims (0.23%) was the second highest of all unintentional causes of deaths due to intoxication.

An Australian study (Bruck et al. 2011) that included 95 victims of fire found positive BAC in 58% of the victims and in 31%, BAC > 0.20%. In another Australian study, fire survivors were compared to those who were deceased (Xiong et al. 2015). Some 10.9% of survivors reported to have consumed alcohol before the fire, but among the deceased, alcohol was detected in 56.4% of the victims. Their BAC levels varied between 0.014% and 0.481% and alcohol-positive victims had a significantly higher risk of dying in residential fires than those who did not consume alcohol (*OR* = 10.58). This implies impaired ability to function in a case of fire and is therefore a direct risk factor of injury or death.

A US study by Neaman et al. (2010) on recreational fires showed that alcohol was associated with a higher risk of hospitalisation and complications. A study from Oklahoma (in the US) showed alcohol to be a risk factor in 31% of fatal fire burns (Levy et al. 2004). Flame burns are also recurrently associated with alcohol consumption. A UK study revealed 60% of the alcohol-related burns were due to flames (Holmes at al. 2010). The same study revealed that in alcohol-related burns, over half of the victims had alcohol dependence while in non-alcohol–related burns this figure was as low as 4.5%.

Alcohol intoxication can also play a role in post-injury medical complications. For instance, it suppresses intestinal immunity and deteriorates gut permeability, resulting in delayed wound healing and longer inpatient time (Choudhry and Chaudry 2008; Molina et al. 2015).

Some authors (Warda et al. 1999; Taylor and Rehm 2006) have highlighted that the combined use of tobacco and alcohol is a significant risk factor for fire-related deaths, especially in residential settings. In this case, alcohol may directly elevate a risk of fire as well as hamper one's ability to avoid injuries once a fire occurs.

3.4.2.3. Other factors

The victim's functional capacity is often affected at the time of injury. Hodgman et al. (2017) analysed a large sample of 20,989 burn patients with drug screen available in the US National Burn Repository. They observed a positive screen for any illicit drug in 55.5% of the patients. Interestingly, half of the patients with a positive drug screen had flame burns. Drug users had slightly larger TBSA (11.2% vs 9.5%) and this resulted in a longer hospital stay than non-users. Xiong et al. (2015) reported a risk ratio of 3.2 of dying in a residential fire among those consuming psychotropic and sedative drugs compared to those who were not. Advanced age is also often associated with functional and cognitive impairment (Langa et al. 2017). Holmes et al. (2017) reviewed 392 elderly burn patients admitted in to a US burn centre. Dementia was present in 18% of these patients and delirium in 39%. On the other hand, in Australia, Harvey et al. (2016) estimated a smaller prevalence of dementia (11.0%) among 1535 elderly patients (65 and older) hospitalised for burn injuries.

Mental disorder is a significant risk factor for burn injury too. Palmu et al. (2010) studied 107 burn patients in Finland, admitted to the Helsinki Burn Centre (overall, 46.7% of patients were admitted with injuries due to flames; in self-inflicted cases, 82% were admitted with injuries due to flames). In this series of patients, as many as 61% were deemed to have suffered from some mental condition during their lifetime. Similarly, McKibben et al. (2009) stated the prevalence in the US of at least one lifetime psychiatric disorder to be some 64–66% of those burn injured and the corresponding figure was 52% in Sweden.

In Wales, George et al. (2016) assessed self-inflicted burns in 2011. In their sample, as many as 85.7% had pre-existing mental health conditions, with depression, anxiety, bipolar disorder, and drug and alcohol abuse being the most prominent. Similarly, in a US study, Pham et al. (2003) observed a 91% rate of pre-existing psychiatric diagnoses among self-inflicted burn victims in a burn centre with almost a half having made previous suicide attempts. Ali et al. (2006) studied 56 self-inflicted burn victims admitted in a burn centre in the UK, which represented some 3.5% of all adult burn admissions. They found the mean TBSA to be 23% with an in-hospital mortality of 25% – an eight-fold excess in comparison to unintentional burns.

Posing stress to the aspect of tertiary prevention, pre-existing psychiatric diagnosis has been shown to significantly prolong hospital stays (Wisely et al. 2010). Tarrier et al. (2005) discuss that further studies would be needed to assess whether a longer duration of care and slower wound healing is associated with biological or behavioural factors. These authors have reported that self-inflicted cases take longer time in hospital and wounds take a longer time to heal (Tarrier et al. 2005).

In Finland, during 2007 and 2008, a total of 67% of seriously injured burn patients had reduced functional or cognitive capacity at the site of fire (Kokki 2009). Alcohol, drugs or medicines were estimated to have played a role in 66% of fire-related deaths and almost the same proportion in severe, non-fatal injuries. In around 40% of the cases the victims either failed to notice the fire or did not react to it in time.

4. COSTS

Fatal and non-fatal fire injuries cause costs directly and indirectly. Direct costs are those resulting in immediate, concrete, tangible costs or losses. These costs include, for example, medical care and the actions of police and rescue services, and in the case of fire, often property losses. Indirect costs indicate (financial) losses due to an injury that did not result in immediate compensation. An example of the indirect costs to society would be productivity loss induced by forfeited work contribution.

4.1. THE CARE COSTS OF BURN INJURIES

Several studies have been conducted on the costs of treating burns. However, relatively few have focused on fire-related burns in particular. It is well established that TBSA and age are the most important predictors of, and have a major impact on, the length of hospital stays and therefore on the associated costs (Hussain and Dunn 2013).

A Canadian study, focusing on the direct cost of fire-related burns, analysed patients treated between 1995 and 2012 (Banfield et al. 2015). The average extent of a burn was 22% and mean care costs per patient reached CAN$ 84,678 (US$ 76,600 in March 2014).

There are several studies on the cost of a burn injury in Europe. According to a Welsh study on three patients (Hemington-Gorse et al. 2008), the treatment of a 31-year-old man who suffered 38% burns in a residential fire cost a total of EUR 485,384. The patient spent 40 days in an intensive care unit, then 50 days in a general ward, from where he was moved to a burn unit closer to his home. During treatment the patient developed sepsis and renal failure, which complicated the treatment. Another Welsh study performed an assessment of the financial implications of self-inflicted burns (George et al. 2016). The authors estimated the total costs of those receiving intensive care at £225,302 per person. A UK study by Jeevan et al. (2014) examined the total care costs of three inpatients with flame burns and TBSA of 8%, 10% and 24%. Their cost estimates came up at, respectively, £21,470 (EUR 27,432 on 31.12.2014), £52,406 (EUR 66,960) and £66,029 (EUR 84,366).

Onarheim et al. (2009) studied all 874 burn patients receiving treatment in Norwegian hospitals during 2007. The average cost of burn treatments per inpatient stay was estimated at EUR 11,800. Santos et al. (2016) assessed 26,447 burn injury admissions during 2000–2013 in Portugal. Flame burns accounted for 40.1% of these cases. The cost per admission reached EUR 8032 in 2013.

A Dutch study (Hop et al. 2016) considered 249 patients with burn injury admitted in a burn centre in Rotterdam between August 2011 and July 2012. The average TBSA of burns was 8% for each patient studied, with a range between 0.2 and 95%. A total of 38.6% of the patients had fire-related burn injuries. The average cost of treatment was approximately EUR 21,000. Additionally, Hop et al. (2014) conducted a systematic review based on estimates from four studies in HICs about the costs of burn care and the reported average care costs of US$ 87,140 for flame burns.

Twenty adult burn patients and the costs of their treatment were examined in an Australian study (Ahn and Maitz 2012). Some 60% of the patients had fire-related injuries, while the others had liquid, contact and electrical burns. The total cost reached AUD 2,449,112 (US$ 2,534,464) for the treatment of burns covering an average of 19.55% of the skin surface. At its most expensive, the cost of treatment rose to AUD 842,419 for a patient with burns covering 62% of the body surface. The authors created a regression model which predicted treatment costs as a function of the extent of the burned skin area, using this to estimate the cost of treating the average burn (7.52%) for the entire population as AUD 71,056.

Some studies on the care costs of burn injuries have focused on a demographic subgroup of patients: paediatrics. Klein et al. (2008) assessed the paediatric burn patients admitted to a burn centre in the US. The average TBSA was, in 2005, 8.2% and the average treatment cost was US$ 9,026. For severe burns (TBSA >= 20%, mean TBSA of 32.7%) hospital mean costs were estimated to be US$ 63,806. Pellat et al. (2010) examined three cases of severe paediatric burns in a burn centre in England. The total care costs of these patients ranged from £55,355 to £74,494 while TBSA ranged between 30 and 40%. In a large-scale study (n = 17,770) in China, Zhu et al. (2013) estimated mean care cost for paediatric patients at RMB 4253 (some EUR 490 on 31.12.2010). However, some 72% of the patients had burns with TBSA < 10%. Another Chinese study by Kai-yang et al. (2009) assessed paediatric scalds in Shanghai. The mean cost was estimated at RMB 7,841 (some EUR 800 on 31.12.2009) with an average TBSA of 8.8%. A South African study (ter Meulen et al. 2016) estimated mean total care costs for flame burn at ZAR 47,234 (EUR 327 in 31.12.2013) during 2013–2014.

Obviously, the cost of care in general also depends on the country. In LMICs, the cost can be much lower than in HICs. Gallaher et al. (2015) studied burn inpatients in Malawi during 2011–2014. The mean TBSA among their patients was 17.9% and the mean length of stay was 23.1 days. The average care cost was only US$ 560. Ahachi et al. (2011) studied the care cost of acute burns in Nigeria. They estimated direct care costs per patient at EUR 932 with an average TBSA of 21%, flame injuries being the most prominent (61.5%). In India, Ahuja and Goswami (2013) reported treatment cost per patient at US$ 1060 with mean TBSA at 42% and mean patient age relatively low at 23 years old.

Karimi et al. (2015) studied burns in Iran over a two-year period (2009–2011). There were 1721 inpatients during the period. Flame burns accounted for 49.8% of cases. The mean TBSA was 17.9% and the mean cost of treatment was US$ 3,740, with the highest cost being US$ 91,000. Another Iranian study by Karami Matin et al. (2012) assessed 388 burn patients admitted to a burn centre. The mean TBSA for the patients was some 36% and the mean costs of care reached IRR 20,463,227 (approximately EUR 1,260 on 31.12.2012). Of these, 67% were flame burns. Yet another Iranian study examined 1425 burn injury inpatients admitted to a burn centre during 2012–2015 (Latifi et al. 2017). Half of the cases were due to flame burns. While average TBSA was not reported, 60% of the cases had TBSA exceeding 11% and nearly a third had TBSA exceeding 23%. In this case, mean hospital costs reached US$ 2766.

Sahin et al. (2011) evaluated burn injuries treated at the Gulhane burn centre in Turkey. They assessed 43 patients with a mean TBSA of 36%. In the case of flame burns, the mean TBSA was 32%. The duration of hospitalisation varied between 26 and 208 days, with a mean hospital stay of 75 days. The cost of flame burns ranged from US$ 764 to US$ 59,614 with a mean cost of US$ 13,849.

Anami et al. (2017) conducted a study on the cost of burn injuries in a burn centre in Brazil during 2011–2013 that consisted of 250 patients, the mean TBSA was 27.9% and the average total cost of hospitalisation reached US$ 39,595.

Mathews et al. (2017) examined the treatment cost related to a mass casualty explosion in a factory in Taiwan in 2015 that resulted in very severe burns among survivors. They found mean TBSA among the patients to be 43.5% with a mean total cost per patient of US$ 50,848 and a mean hospital stay of 57 days.

The striking contrast between cost estimates in HICs and LMICs was reported by Hop et al. (2014) as well. They estimated the total healthcare cost for a burn injury in an HIC at US$ 88,218 while it was US$ 5,196 in an LMIC, a nearly 17-fold difference.

Table A. Summary of cost studies.

The authors	Country	Year of publish	Sample size	(mean) cost per case	TBSA	Additional relevant info if available
Banfield et al.	Canada	2015	n=1139	CAN$ 84 678 per patient	mean 22%	
Onarheim et al.	Norway	2009	n=874	EUR 11 800	NA	
Santos et al.	Portugal	2006	n=26447	EUR 8032	mean 10%	
Jeevan et al.	UK	2014	n=3	£21 470 (EUR 27 432) £52 406 (EUR 66 960) £66 029 (EUR 84 366)	8%,10%,24%	
Hop et al.	the Netherlands	2016	n=249	EUR 21000	mean 8%	38.6% of the cases fire-related
Hop et al.	the Netherlands	2014	4 studies	US$ 87 140		Systematic review
Ahn & Maitz	Australia	2012	n=20		mean 19.55%	60% of the cases fire-related
Klein et al.	US	2008	n=654	US$ 9 026	mean 8.2%	paediatric population
Pellat et al.	UK	2010	n=3	range £55 355 to £74 494	range 30% to 40%	paediatric population
Zhu et al.	China	2013	n=17770	EUR 490	72% of the cases TBSA < 10%	paediatric population
Kai-yang et al.	Chine	2009	n=113	EUR 800	mean 8.8%	limited to scalds
ter Meulen et al.	South Africa	2016	n=72	EUR 327	NA	flame burns
Gallaher et al.	Malawi	2015	n=905	US$ 560	mean 17.9%	
Ahachi et al.	Nigeria	2011	n=52	EUR 932	mean 21%	61.5% flame burns
Ahuja & Goswami	India	2013	n=797	US$ 1 060	mean 42%	
Karimi et al.	Iran	2015	n=1721	US$ 3 740	mean 17.9%	49.8% flame burns
Karami Matin et al.	Iran	2012	n=388	EUR 1 260	mean 36%	67% flame burns
Latifi et al.	Iran	2017	n=1425	US$ 2 766	60% of the cases TBSA>11%	
Sahin et al.	Turkey	2011	n=43	US$ 13 849	mean 36%	
Anami et al.	Brazil	2017	n=250	US$ 39 595	mean 27.9%	
Mathews et al.	Taiwan	2017	n=48	US$ 50 848	mean 43.5%	
Hop et al.	International	2014		US$ 88 218 in High Income countries, US$ 5 196 in Low and Middle Income Countries		
Hemington-Gorse et el.	Wales	2008	n=1	EUR 485 384	38%	
George et al.	Wales	2016	n=21	£ 225 302		self-inflicted

4.2. INDIRECT COSTS

The main method for evaluating productivity losses due to injury or death are the human capital (HC) and friction cost (FC) methods. In the HC method, all productivity is assumed to be lost during the period of illness, lasting until the patient's retirement age or premature death in relation to the retirement age. The FC method limits the lost productivity to the friction period, which is the time period required to replace a sick individual at her or his workplace and for a new employee to take over the patient's work. Therefore, in short-term illness, the HC and FC methods will provide similar estimates on productivity losses whereas in cases of long-term illness or death, the FC method will estimate much lower productivity losses than the HC method (Kigozi et al. 2016; van den Hout 2010).

There are a variety of studies examining indirect costs due to diseases and injuries. However, studies concerning indirect costs induced specifically by fire-related injuries are scarce if not completely lacking. However, there are some studies assessing indirect costs due to burn injuries in general. Moreover, a few studies on the indirect cost of other injuries will be mentioned in order to appreciate the magnitude of the burden caused by injuries.

A Dutch study (Hop et al. 2016) assessed the productivity losses induced by burn injuries by applying the FC method (Koopmanschap et al. 1995). Costs incurred during a three-month period following injury were assessed. By this method, the authors obtained indirect costs for lost productivity due to a burn injury that exceeded EUR 5300. Another study from the Netherlands assessed indirect burn injury costs by using the FC method (Goei et al. 2016) but with a two-year follow-up. In this case productivity losses exceeded EUR 8500. In their study, indirect costs incurred some 30% of overall patient costs. Yet another study from Netherlands assessed bicycle-related traumatic brain injuries (Scholten et al. 2015). They observed indirect costs to be EUR 16,520 for males and EUR 11,990 for females. It seems that the productivity-related burden of a burn injury is sizeable, but it is similarly so in the case of, for example, hip fractures.

Anders et al. (2013) assessed the direct and indirect costs of severe trauma in Germany. They observed the indirect costs due to lost productivity to be some EUR 13,800 based on using the HC methodology. Polinder et al. (2016) assessed the burden of a variety of injuries. Productivity losses ranged from EUR 696 for lower extremity injuries to EUR 34,518 for hip fractures. A Spanish study estimated indirect costs to be some 80% of total costs although it included fatalities, which cause major indirect losses (Sanchez et al. 2008).

Similarly to direct costs, indirect costs are heavily subject to country variation. In China, the indirect cost of a fatal injury in terms of lost productivity was estimated at US$ 20,171 (Fang et al. 2016). For a non-fatal injury they estimated the indirect cost to US$ 2276. In Iran, Kavosi et al. (2015) studied the economic burden of deaths due to traumatic brain injury following fatal traffic accidents. They estimated productivity losses due to death at US$ 73,300.

4.3. THE CARE COST OF COMBUSTION GAS POISONINGS

No studies have been conducted on the costs and burden of fire-related combustion gas poisoning. However, some studies have addressed non-fire-related CO poisoning.

In the US, Iqbal et al. (2012) studied unintentional CO poisonings unrelated to fires. In 2007 they observed 2302 cases of poisoning that needed inpatient treatment. The average treatment period was 4.9 days and the average cost of treatment was US$ 11,381. In the US, Miller and Bhattacharya (2013) assessed CO poisonings among all age groups during 2007 and found the mean hospital cost to be US$ 15,769. Another US study assessed the costs of unintentional non-fire–related CO poisonings and the cost and benefits of CO detectors. They estimated the average cost of hospitalisation for each admission to range from US$ 9554 to US$ 11,678 during 2010–2014 (Ran et al. 2017).

In Turkey, the intensive care unit (ICU) costs of acute CO poisoning were estimated to be US$ 1062 (Sut and Memis 2008). However, this estimate only partially represents the costs at the treatment for CO poisoning as it may continue elsewhere after the ICU phase.

5. THE PREVENTION OF FIRE-RELATED INJURIES AND DEATHS IN FINLAND

In Finland, preventive measures have been introduced and implemented during the past three decades to reduce fire injuries. At the beginning of the 1990s, specific fire safety requisites were introduced for mattress and upholstered furniture (seats, chairs), according to which they cannot be easily ignited by burning cigarettes. However, the effectiveness of such preventive measures has been limited by the abundance of old furniture that does not fulfil these requirements and by the import of furniture from countries that do not have similar fire safety requirements. Sheets and other fabrics that ignite with difficulty are only diffusely used in hospitals and hotels. Smoke alarms became mandatory in every house and apartment in September 2000 and cigarettes have had to be self-extinguishing since April 2010 (Rescue services 2019a, 2019b). Basic legislative provisions on smoke alarms are nowadays mentioned in the Finnish Rescue Act (Act 379/2011) and the Ministry of Environment Decree on Fire Safety of Buildings (Decree 848/2017) whereas specific provisions – for instance on their number, placement and maintenance – are listed in a decree of the Ministry of the Interior (Decree 239/2009) and their technical requirements in a decree of the Council of State (Decree 291/2009). As for self-extinguishing cigarettes, the main legislative provision is found in the Tobacco Law (Law 549/2016, § 13).

More in general, a crucial law for fire prevention is the Finnish Rescue Act (Act 379/2011). The purpose of this act is to improve the safety of people and to reduce the number and the consequences of accidents. This act lays down specific provisions on the duty of individuals, enterprises and other organisations (among others) to prevent fires (with subjects ranging from handling fires to the fire safety and evacuation plan in building and safety equipment, e.g. fire alarms and their maintenance), as well as to prepare operations for once a fire occurs and to limit its consequences (via the organisation of rescue services and departments at national and regional levels; the responsibility of rescue departments and services in supervisory activities and for providing education and advice to various parties; and the practical aspects of rescue operations and training). Actually, the Ministry of the Interior's Department for Rescue Services leads and supervises rescue services, maintains oversight of their coverage and quality, and is in charge of their preparedness and organisation at the national level (Rescue Services 2019c). The country is divided into 22 rescue service regions designated by the government, each with a rescue department with operational, supervisory and educational duties at regional level; within each region municipalities have joint responsibility for rescue services (Rescue Services 2019d). A reform proposal (HE 64/2018) of the Finnish Rescue Act has been recently approved (November 2018); one of the main changes of this reform will be that, starting from 2021, the 18 Finnish administrative provinces will have a rescue department to organise rescue services

Indirectly, the Act on Supporting the Functional Capacity of the Older Population and on Social and Health Care Services for Older Persons (Act 980/2012) aims to promote wellbeing and functional capacity, as well as to prevent illness and injury among the elderly, also has implications for fire safety and prevention.

There are also non-governmental safety organisations which act in support of the authorities. The Finnish National Rescue Association (SPEK) is a non-profit organisation with expertise in fire and rescue services, emergency planning and civil protection that focus on developing residential safety and promoting the voluntary activities of rescue services (SPEK 2019).

Monitoring fire safety-related issues. In Finland, risk factors for fire, the causes of fires, rescue service operations, and fire-related mortality and morbidity are constantly monitored through a number of data sources. The resource and accident statistics system of the rescue services (Statistical Data System of Finnish Rescue Services [PRONTO]) is maintained by the Department for the Rescue Services of the Ministry of the Interior and the Emergency Services College (ESC) for the monitoring and development of rescue operations and accident investigation. The system includes data on fires, fire hazards and rescue operations, collected by regional department for rescue services (Ministry of the Interior 2018). PRONTO also includes data from fire investigation reports that are created each time a death or a serious injury due to fire occurs. For instance, in a residential fire such a report describes and analyses the type of building involved, the cause of fire and ignition, and its progression, as well as structural fire safety issues and the actions taken by the fire brigade. Such information enables the rescue services to better assess risks and plan appropriate preventive measures (Kokki and Jäntti 2009).

Statistical data extracted from PRONTO have also been employed for brief reports published by the ESC (Rescue Service 2018) and – together with media monitoring – by SPEK (2019).

In addition to these, SF maintains detailed annual statistics on causes of death, including those related to fire (see Section 3.3.1) and the THL also maintains a statistics website on fire-related accidents (THL 2019) which includes epidemiological data on fire-related injuries based on the FHDR (see Chapter 3.3.2.), including inpatient care and day surgeries.

In addition to Finland, internationally, countermeasures for fires are implemented. For example, in Scotland, high rise building must be made of noncombustible materials and cladding systems incorporated with existing buildings. Additionally, all care homes must have sprinkler systems as well as in England with tower blocks higher than 30 meters. In Ireland, a fire safety certificate is required before the building process. In Germany, fire protection is needed in buildings with floor level exceeding 7 meters. In Italy, approval from local fire authority is needed before construction can proceed while in Sweden fire safety strategy document is required in order to start construction (de Castella 2017).

Aside of structural issues, smoke alarms are one of the most important fire prevention utility worldwide. However, legislation concerning smoke alarms varies by country. In the UK, private sector landlords are required to have at least one functioning smoke alarm on every storey (Ministry of Housing, Communities & Local Government 2015). In the US, the majority of the states require smoke alarms installed and the most of them require alarms hard wired in new constructions (First Alert 2019).

Also in addition to Finland, fire safe cigarettes are also implemented in various countries. In the US, all 50 states require cigarettes to be self extinguishing (Yau and Marshall 2014). In the EU, 17th November 2011 new standard of cigarettes to be self extinguishing was set to concern all of EU (European Comission 2019). This was some year after Finland's implementation.

6. THE AIMS OF THE STUDY

This study is a register-based analysis of severe (i.e. requiring inpatient care or leading to death) fire-related injuries and their burden in Finland.

The main aims of this study are to:

1) investigate the epidemiology of fatal and non-fatal fire-related injuries in Finland (Articles I, II, IV)

2) estimate the direct costs of fire-related injuries (Article III, unpublished data)

3) estimate the indirect costs due to fire-related injuries and deaths (Articles IV, V).

7. MATERIALS AND METHODS

7.1. DEFINITIONS OF FIRE-RELATED INJURIES

Fire-related injuries are injuries caused by fire, flames and the associated combustion gases. As the study is register-based and the register is structured on the basis of the coding system provided by the International Classification of Diseases (ICD), we defined *fire-related injuries* as shown in Table 1.

Table 1. International Classification of Diseases 10th version (ICD-10) external cause and injury codes for fire-related injuries

ICD-10 code	Meaning
External cause codes	
X00-X09	Exposure to smoke, fire and flames
X76	Intentional self-harm by smoke, fire and flames
X97	Assault by smoke, fire and flames
Y26	Exposure to smoke, fire and flames; undetermined intent
X47	Accidental poisoning by and exposure to other gases and vapours
Injury codes	
T20-T32	Burns and corrosions
T58	The toxic effect of carbon monoxide
T59	The toxic effect of other gases, fumes and vapours

The inclusion criteria of fire-related injuries in FHDR data:

- External cause codes: {X00-X09, X76, X97, Y26}
- The external cause code refers to accidental poisoning by and exposure to other gases and vapours (X47), while the nature-of-injury code covers burn injuries (T20–T32)
- 'Nature of injury' refers to burn injuries (T20–T32) and simultaneous combustion gas poisoning (T58–T59).

The inclusion criteria of fire-related deaths in cause-of-death statistics:

- External cause codes: {X00-X09, X76, X97, Y26}.

7.1.1. THE FINNISH HOSPITAL DISCHARGE REGISTER

The FHDR was used as the core data for the study. The FHDR is an official register maintained by the THL (THL 2019b). The purpose of the FHDR is to gather information on the activities of health centres, hospitals and other institutions with patient places, and the customers that they treat, for statistical, research and planning purposes. The FHDR includes information on the periods of day surgery that require inpatient care in Finland. Outpatient care in specialised health care is also covered by the FHDR.

Since 1996, the injury and external causes codes entered in the FHDR have complied with the ICD's 10th version (ICD-10) (World Health Organization 1990). The THL has an injury-assessment tool, FINJURY, which includes all FHDR records logged as an admission for injury and/or characterised by an external cause code. In this study, FINJURY was used to assess outpatient admissions during the period 2006–2014.

7.1.2. INPATIENT CARE COSTS

Cost data on inpatient treatment periods was obtained from three sources. The total care cost for each individual hospital stay was obtained. Cost data on treatment at the Helsinki University Central Hospital were available from the registers of the THL as total cost per each care period. Similar information from Kuopio University Hospital was obtained in response to a request for data. These data from burn centres comprehend period of 2001-2009. The remaining (other than Helsinki and Kuopio) comprehensive, country-wide cost data was obtained as an outcome of the "PERFECT" (Performance, Effectiveness and Cost of Treatment episodes) project, implemented by the THL, the university hospital districts and the Social Insurance Institution of Finland (THL 2019a). The separate acquisition of cost data for Helsinki and Kuopio is based on the fact that these hospitals had, at the time of the study, Finland's only two specialised burn centres, which treat the most challenging cases based on higher-level, specialised expertise. The best practically obtainable cost estimates for the most challenging cases were secured in this manner. The data of the PERFECT project was used as collecting cost data separately from each hospital and health care unit (other than Helsinki and Kuopio) in Finland would be practically impossible due to a large numer of operators.

7.1.3. CAUSE-OF-DEATH STATISTICS

Statistics on causes of death are maintained by SF (Statistics Finland 2017). Such data are based on information on death certificates, which is complemented with data from the Population Register Centre's Population Information System. Statistics on causes of death cover people who have died in Finland or abroad but were domiciled in Finland at the time of their death (Statistics Finland 2017). As additional information, SF provided demographic information on individuals (data on age, gender, place of residence, income, professional status and whether the forensic pathologist deemed that alcohol contributed to the death). The WHO ICD-10 (World Health Organization 1990) disease classification was used to categorise the causes of death (Table 1). Forensic investigation and autopsies were performed for over 98% of fire-related deaths (Lunetta et al. 2007).

7.1.4. SOCIAL BENEFITS

The Social Insurance Institution of Finland (Kela), the Finnish Centre for Pensions (ETK) and the Workers' Compensation Centre (TVK) provided data on benefit records attributable to injuries and records of statutory work accident insurance for those injured at work. Kela provided data on the following four types of benefits: disability pensions, sickness allowances, rehabilitation provided by Kela and disability compensations. The ETK provided data on pensions and rehabilitation compensations. In these data, an indication of the nature of the injury is given in accordance with the ICD-10, similarly to the FHDR. The TVK provided the number of days within each compensation period for those injured in an occupational accident. Data from each of these instances were obtained using personal identification numbers found in the FHDR for those with a fire-related injury. The data were fetched from Kela, ETK and TVK using these identifiers hence capturing all records for those identified as injured by the FHDR. Benefits themselves were not of interest per se but were used as a proxy to estimate the disability time period following the injury in order to assess the potential lost productivity accumulated during the period by the Human Capital approach.

7.1.5. THE SAMPLE FROM THE HELSINKI BURN CENTRE

An extract from documentation on patients with fire-related injuries was obtained from the Helsinki Burn Centre, which was the largest burn centre in Finland at the time of the study. The extract covered all information retrievable at the time of acquisition on patients injured between 2001 and 2005 (n = 222). It provided information on the cause of the accident (e.g. residential fire, open fire, burning liquids) and, in particular, the extent of the burn. The reason of obtaining a separate sample was to get more detailed information on mechanisms (beyond diversity of ICD-10) and especially information on TBSA which is a key variable in determining burden of burns.

7.2. REGISTER LINKAGE

The Information Systems Unit of the THL converted the personal identification numbers included in the data into unique number sequences which concealed the IDs from the researchers. The researchers were able to combine register data from different sources by using this numbering, which was deemed as the same across all of the data. At the request of SF, its data on the causes of death was not combined with other care data and this material did not include personal identification numbers. This prevented further analyses of deaths of those who died during care and therefore exist in both FHDR and Causes of Death data. However, such analysis was not any of the primary purposes of the study. Register linkage was implemented as detailed in the section "Use of data" below and in Table 2.

7.3. USE OF DATA

The data sources used in the different studies are presented in Table 2.

Table 2. A summary of the data sources used in the different studies.

	Topic	Data used	Years
Study I	The feasibility of using core data	Finnish Hospital Discharge Register	1996–2009
Study II	Epidemiology and a description of fire-related injuries	Finnish Hospital Discharge Register, a sample from the Helsinki Burn Centre	2000–2009
Study III	The inpatient care costs of fire-related injuries	Finnish Hospital Discharge Register, cost data from Helsinki University Hospital and Kuopio University Hospital, cost data from the PERFECT project, a sample from the Helsinki Burn Centre	2001–2009
Study IV	Indirect costs (productivity losses) due to fire-related deaths	Cause-of-death statistics supplemented by socio-economic data from the population register	2000–2010
Study V	Other indirect costs (productivity losses) due to fire-related injuries	Finnish Hospital Discharge Register, Social security data from the Finnish Centre of Pensions and Social Insurance Institution of Finland, work accident compensation days from the Workers' Compensation Centre	2001–2010

7.4. STATISTICAL METHODS

In Study I (on the feasibility of the core data), basic percentages and trends in percentages were used to compare recording practices during time. Additionally, a smoothed hazard function was applied in order to approximate the risk of re-admissions in relation to time. In Study II (on the epidemiology of fire-related injuries in Finland), trends in incidence rates within age groups during 2000-2009 were analysed using a Poisson regression, always adjusted for the relevant population sizes in each population group at risk. The generalised additive model was used to explore the relationship between age and the cause of injury. Means, medians, percentages, ranges and interquartile ranges were used to describe the relevant quantities. In Study III (on inpatient care costs), arithmetic means, medians and 95% confidence intervals (CIs) via the bootstrap percentile method for cost estimates were used. A test, based on the Wilcoxon test, was performed for some sample distributions of injury severity. In Study IV (on the indirect costs of fire-related deaths), arithmetic means, medians and percentages of cost estimates were used to describe the results. A Kruskal-Wallis test was implemented in order to test regional differences. A quantile regression was applied for age trend testing. CIs (95%) were obtained using a bootstrap percentile method. In this study (Study IV), CIs reflect the stability of the estimates derived from the data rather than "true" statistical random variation, since the data is equal by definition for each age and gender point, and therefore lacks "true" random variation. In Study V (on the indirect costs of fire-related injuries), arithmetic means, medians and percentages were used to describe the relevant quantities.

Statistical and data analyses were performed using R-software, versions 3.2.2 and 3.4.1 (R Development Core Team2010).

7.5. THE HUMAN CAPITAL METHOD

In order to estimate the indirect societal costs of injuries, the HC method was used. This method is widely used in scientific "cost of illness" studies. The method quantifies societal cost as future productivity lost due to injuries by discounting future expected productivity (as if the person would not have died or been injured) from the present value (Landefeld and Seskin 1982). Using the standard HC method, estimates are constructed from a societal perspective; lost labour production forms part of societal productivity. It is often the case that lost productivity includes both lost labour productivity and lost household work. When quantifying losses, some population-level income statistics are often used. We used age- and gender-specific income data, adjusted by labour force participation rates and selected discount rates. In our studies, the HC method was applied in order to cover both forgone earnings (labour productivity) and household work, while discount factors of 1%, 3% and 6% were applied.

7.6. ETHICAL APPROVAL

The Research Ethics Committee of the THL approved the performance of the research (decision 1/2011: § 279/2011, 27.01.2011). None of the sub-studies required individual consent since the research data were anonymous and no individuals were contacted at any time.

8. RESULTS

8.1. THE EPIDEMIOLOGICAL FEATURES OF FIRE-RELATED INJURIES (STUDIES I, II AND IV)

8.1.1. FIRE-RELATED INJURIES RESULTING IN DEATH

Fire-related deaths were studied over an 11-year period from 2000 to 2010, based on SF's cause-of-death data, the related socio-economic data and life expectancy. A total of 1,090 fire-related deaths were observed during the research period, an average of 99 deaths per year, indicating an incidence of approximately 18 deaths per million of the population. The majority of the deceased were males (76%), with females accounting for 24%. Females were older on average (57 years old versus males average of 52 years old). One in four of the victims were over retirement age (commonly 65 years old) at the time of death.

The main underlying cause of death was combustion gas poisoning (65%), followed by burns (33%). The remaining 2% included miscellaneous injuries. Most of the deaths were accidental (81%), while 13% were suicides, 3% homicides and 4% remained of undetermined intent. Alcohol was a contributing factor in approximately 60% of the cases, but among middle-aged males, as many as four out of five deaths were alcohol associated.

Marital status at the end of the year preceding death was that 82% were *widowed, divorced* or *single* (in this context: *unmarried*). The employment rate for the entire group was 19%, with 17% being unemployed and 52% having retired for various reasons. A total of 6% were students or children under 15 years of age. The rest 4% were assigned by data provider as out of workforce for other reasons.

PYLL ranged between 2094 and 3299 years per year during 2000–2010, with an average PYLL of 2763 per year. There was a decreasing trend in average PYLL per person. This decreased from 34 years (CI: 31.4–37.0) in 2000 to 25 years (CI: 22.1–26.9) in 2010. The victims' age distribution has a significant effect on PYLL. The median age was found to increase from 43.5 in 2000 to 59.5 in 2010, while the first quartile for age increased from 33.3 in 2000 to 47.0 in 2010 (linear trends $p < 0.001$).

8.1.2. FIRE-RELATED INJURIES RESULTING IN INPATIENT CARE

FHDR data shows that there were 2953 fire-related injuries leading to inpatient care during the 10-year period of 1.1.2000–31.12.2009, which gives an average of almost 300 cases a year in a population of nearly 5.5 million. The main type of injury recorded was burn injuries (n = 2284, 77%), followed by combustion gas poisoning without a recorded burn injury (n = 495, 17%). The remaining 6% had other injuries. Figure 1 shows the incidence of burn injuries in Finland 2000 through 2009.

Most of the people injured were males (74%, females 26%). The mean (median) age for males was 40.4 (41.0) years and 50.4 (51.0) for females. The age ranged between 0 and 97 years old.

Most of the cases were accidental (95.2%), but the remainder (4.8%) were due to self-harm.

When fire-related injuries were examined separately for burn injuries and combustion gas poisonings, distinct opposite trends were observed. Among fire burns, the incidence decreased from 5.4/100,000 persons in 2000 to 4.0/100,000 persons in 2009 ($p < 0.05$). This decreasing trend is mainly accounted for by the reduction in such injuries among males and, more prominently, among younger males. On the other hand, combustion gas poisonings increased from 0.6/100,000 persons in 2000 to 1.5/100,000 persons in 2009 ($p < 0.05$).

In-hospital mortality among patients with fire-related injuries represented 6% of all admissions (n = 165, yearly range 11–20). Eighty six per cent of deceased patients had sustained a burn injury.

The overall mean (median) length of stay was 16.6 (5.0) days, ranging from 1 to 422 days (fire-related burn injury) days among all fire-related injuries. Among fire burn injury patients, the mean (median) length of stay was 19.6 (7.0) days and 4.6 (1.0) days among combustion gas poisonings, ranging between 1 and 100 days. For those who died during care, the mean (median) length of stay until death was 18.3 (3.0) days.

Most burn injuries needed care in a university hospital (55%) or district/central hospital (38%), whereas 7% were managed in health centres. Among combustion gas poisonings, care was most often provided at a district/central hospital (46%), followed by a university hospital (36%) care and least often at health centres (18%).

Among a series of patients (n = 222) with fire-related injuries treated at the Helsinki Burn Centre during 2001–2005, three specific types of mechanisms of injury were observed: house fires; incidents involving barbeques, grilling, campfires etc.; and incidents involving the use of flammable substances as accelerants. House fires were mainly associated with older age (i.e. 50+), while the two other mechanisms were more frequent in people aged less than 50 years old. The mean (median) TBSA burned was 21.7% (15.0%), ranging from 0.3% to 96.5%. The mean

TBSA for house fire patients was 28.2%, while for incidents involving campfires, barbeques etc. it was 17.4% and for incidents involving flammable substances it was 16.5%. The medians of these TBSA were 21.0%, 15.5% and 11.0% respectively. At least 12 patients had sustained inhalation injuries, 10 of which as a consequence of house fires.

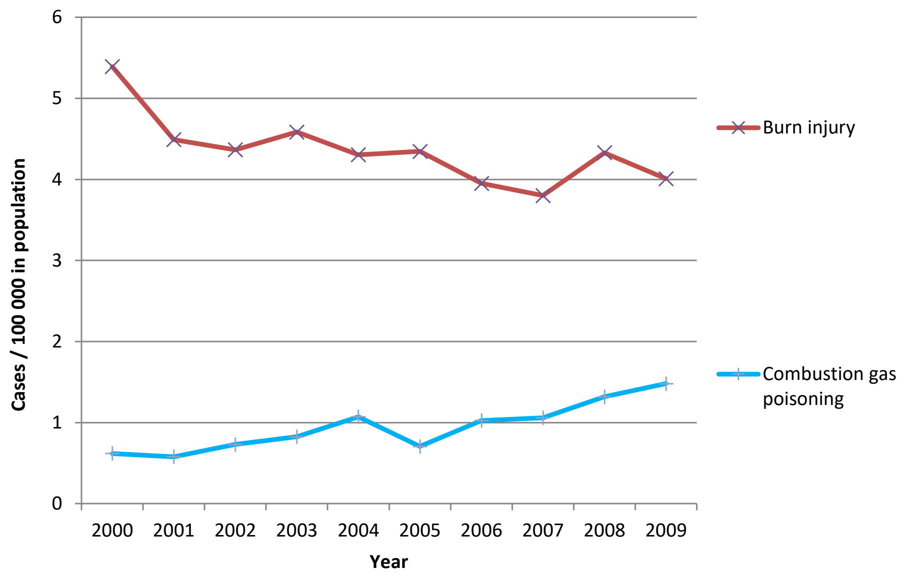

Figure 1. The incidence of fire-related injuries (burns, combustion gas poisonings) during 2000–2009.

8.1.3. FIRE-RELATED INJURIES IN THE CORE DATA

The feasibility of using the FHDR data to study fire-related injuries was assessed as it is the key data of the present study. The main issue to be assessed was the extent to which fire-related injuries could be identified using ICD-10 external cause codes (E-codes). The coding practice in the FHDR during the period 1996–2009 was examined using nature-of-injury codes for burns and combustion gas poisoning. Shortly after the introduction of ICD-10 in 1996, a very high number of E-codes were missing from the records. The proportion of missing E-codes among overall burn injury records was as high as 65.6% whereas the proportion of missing E-codes among combustion gas poisonings was 77%. In the middle of the study period, after 2004, the proportion of missing codes was less than 10% among burn injury records and 11% or lower among combustion gas poisonings. In 2009, the figures were that 2.3% E-codes were missing among burns and 10% were missing among combustion gas poisonings. However, the use of unspecific E-codes (X58: exposure to other specified factors; X59: exposure to an unspecified factor) has increased from 1.9% in 1996 to 11.4% in 2009 among burn injury records. In the case of combustion gas poisonings, the figures rose from 0% in 1996 to 11% in 2009.

After 2000 the strikingly large proportion of missing E-codes prominent in the 90's diminished and stabilised. Since then, the fraction of codes identified as fire-related has remained fairly constant (Figure 2). We therefore decided that the earliest suitable year for research would be 2000.

In the sub-study, feasibility of the core data, the issue warranting further research with consecutive records in the register data was examined and the outcome is following. Episodes of consecutive care records were constructed into care episodes when the admission date of the latter record was no more than two days after the discharge date of the former record. A patient may have visits to a hospital with longer interval (i.e. years). In these cases, care was assumed to relate to the same injury if the time lapse from the previous admission record was two years at the maximum. When operating with care episodes, records of psychiatric care were excluded from the results as it is disputable whether psychiatric conditions are caused by the accident or pre-existing conditions.

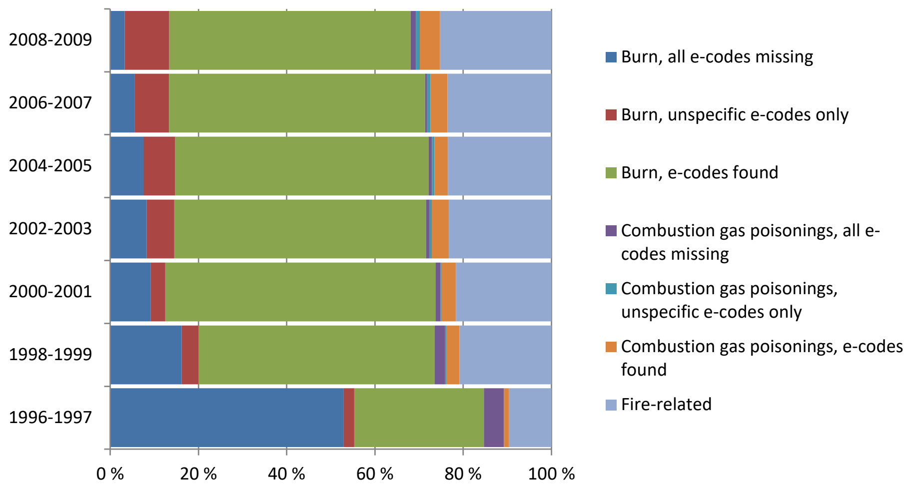

Figure 2. Patterns of E-coding in the FHDR for burn injuries and combustion gas poisonings, 1996–2009. Burns; ICD-10:T20-T32, Comb.gas.pois;ICD-10:T58-T59,Fire-related:Table 1.

8.2. THE COST AND BURDEN OF FIRE-RELATED INJURIES (STUDIES III, IV, V)

8.2.1. THE COST OF INJURIES LEADING TO DEATH: INDIRECT COSTS

Total productivity losses for 2000–2010 reached EUR 342.3 (330.3–354.4) million with a 3% discount rate. Due to use of Human Capital method, based on a 1% discount rate, the figure is some 35% greater, and with a 6% discount rate it is some 29% smaller. Based on a 3% discount rate, yearly productivity losses ranged from EUR 24.5 (21.3–27.8) million to EUR 36.9 (33.1–40.8) million. The mean yearly total loss was EUR 31,12 million according to a 3% discount rate. Losses were highest among young people, particularly females, and varied between some EUR 797,000 in young females and some 91,000 in elderly males (Table 3). Average PYLL was 25 years per death at the end of the study period (2010).

Table 3. Productivity losses by age and gender in euros due to fire-related deaths by Human Capital method.

Age	Male	Female
0–17	581 000	685 000
18–30	626 000	797 000
31–40	510 000	683 000
41–50	366 000	520 000
51–65	212 000	349 000
66+	91 000	151 000
Overall	294 000	379 000

8.2.2. DIRECT COSTS: INPATIENT CARE

The inpatient treatment costs of fire-related injuries were investigated for the period 2001–2009. A total of 2723 cases of fire-related injuries were observed, of which 74% of the injured parties were male and 26% female. On average, the males were younger than the females (41 versus 50 years old) and the age distribution varied between 0 and 97 years. Almost four out of five (77%) of the injuries were fire-related burns and most of the others were combustion gas poisonings (17%). The remaining cases involved miscellaneous burns.

The annual cost of treatment for all inpatient care for fire-related burns was around EUR 5.7 (95% CI: 5.2–6.2) million for the first treatment episode and increased to EUR 6.2 (95% CI: 5.7–6.7) million when taken treatments following the acute stage into account. Injuries involving fire-related burns (n = 2093) cost around EUR 5.9 million a year while the treatment of combustion gas poisonings (n = 463) cost EUR 0.19 million a year.

The average cost per patient was EUR 18,800 for the first (the most acute) treatment episode and EUR 20,400 when the subsequent later admissions were included. The first treatment episode for patients with fire-related burn injuries cost an average of EUR 23,400, which rose to EUR 25,400 when later re-admissions were included. Correspondingly, the first treatment episode in the case of combustion gas poisonings cost EUR 3400, rising to EUR 3600 when re-admissions were included.

Treatment costs strongly depend on the extent of the burns. The average treatment period per %TBSA was 2.7 days (95% CI: 2.4–3.7, n = 168). Correspondingly, the median was 1.6 days (95% CI: 1.3–1.9) per %TBSA. The average cost per %TBSA was EUR 3000 (95% CI: EUR 2600–3500), with a median of EUR 2,120 (95% CI: EUR 1690–2400). Because complications are often associated with extensive burns, the resources required per %TBSA unit increase more rapidly than linearly as the extent of the burn increases (Figure 3). In the case of fire-related injuries covering more than 50% of the body surface area, the average cost of treatment rose to almost EUR 300,000, at a cost of around EUR 4900 per %TBSA unit. The patient's age also has a major impact on treatment costs. For patients older than 60, the cost per %TBSA was more than twice that of patients who were under 60 (the cost being EUR 5600 and EUR 2600 respectively).

The distribution of the treatment costs was strongly skewed to the right (average EUR 25,400, median EUR 6700, maximum EUR 619,000). In extreme cases, the treatment of five patients with fire-related injuries cost over EUR 400,000, when the treatment cost of five correspondingly extreme cases of combustion gas poisoning exceeded EUR 48,000. In sum, around 7–8% of the highest treatment costs accounted for half of all annual costs.

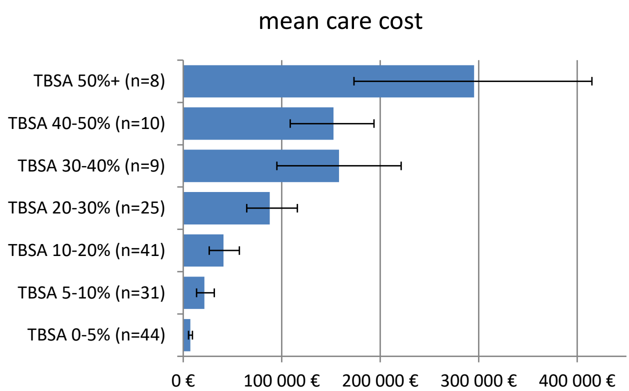

Figure 3. The average treatment costs for fire-related burns according to the extent of the injury (%TBSA).

8.2.3. INDIRECT COSTS: INJURIES REQUIRING INPATIENT CARE

Disability periods

For determining the period of disability, we used the time lapse between the beginning of the first period of inpatient care and the end of the last relevant benefit.

For those with recorded benefits, the median period of disability exceeded two months (63 days). Six per cent (25 out of 410) of those who received benefits or 2% of all cases (25 out of 1503) had a declared disability or one expected to last for 10 years or more.

For those who had no recorded benefits, imputed mean values based on existing duration values were used due to missing data on post-discharge contingency. Among these patients, the mean/median period of disability was 63/36 days.

According to available register data, 27% (410 out of 1503) of the cohort patients received a social, work-related or health care benefit that was possibly related to the injury. Twenty-one per cent received a sickness allowance while 6% received other benefits without a sickness allowance. Among working age persons, 35% received allowances, which approximately implies a similar employment rate. Some 5% of cases were work-related injuries as they show up in the Statutory Accident Insurance.

Benefits and allowances

The total benefits paid for all cases involving burn injuries or combustion gas poisoning ranged from EUR 699,000 to EUR 1.35 million annually, with an overall annual average of EUR 1.03 million. The total amount for the five-year cohort reached EUR 5.15 million. This corresponds to EUR 3430 per person among all patients and to EUR 15,940 among those who received benefits (other than work injury insurance compensation).

Productivity losses

The annual burden of fire-related injuries was estimated using the HC approach for productivity losses to measure potentially lost productivity and household work. Total productivity losses for the entire cohort of 2001–2005 were EUR 28.6 million, giving a mean loss of EUR 19,070 per patient and EUR 5.7 million per year.

8.3. TOTAL BURDEN

Our estimate of the total annual burden of fire-related injuries and deaths exceeded EUR 43 million. Some 15% of this was due to direct care costs while indirect costs due to deaths constituted some 72% and indirect costs due to disability following injury accounted for 13% of the total costs. The total burden presented here represents a conservative estimate as all intangible costs are omitted, although, according to many studies, they may yield a considerable burden.

8.4. OUTPATIENT CARE (UNPUBLISHED DATA)

The majority of burn injuries are treated in outpatient care. However, injuries manageable through outpatient care are often mild in nature and therefore easier to treat and they require less resources than those with inpatient care. However, due to the limited availability of data we could only assess cases severe enough to have been treated as outpatient admissions in specialised health care and treatments in primary health care were omitted. Therefore, this assessment does not cover all outpatient care due to these injuries. However, burns treatable in the outpatient setting of primary health care are expected to be marginal.

Based on the FINJURY database that covers all care periods in specialised health care in Finland and is maintained by the THL, during the period of 2006 to 2014, an average of 288 patients per year were treated for combustion gas poisoning in outpatient specialised health care. The number of patients varied from 188 in 2006 to 433 in 2014. The evaluation of combustion gas poisonings that are specifically due to fire is challenging since a large proportion of such injuries are classified as having a cause that is “other or undetermined” and a high number of records lack a specific E-code. Fire-related cases can be considered a relatively marginal group. In recent years (2010–2014), an average of 93 outpatient visits were made annually due to combustion gas poisonings that were recorded as fire injuries, which covered 41% of all combustion gas poisonings with a given E-code. However, during this period some 37% of combustion gas poisonings had missing E-codes. If it is assumed that the missingness is completely random in distribution and 41% of missing records involve fire-related combustion gas poisonings, the yearly average (during 2010–2014) would total 148 visits and some 137 patients. Among these, some 85 patients a year were of working age.

During 2006–2014, an average of 2420 patients a year required outpatient care in specialised health care for burn injuries. These accounted for an average of 7260 outpatient visits annually. In recent years (2010–2014), there was an average of 568 outpatient visits due to burn injuries recorded as fire injuries. This covers some 10% of all recorded burn injuries with a non-missing E-code. During this period, some 29% of burn injuries had missing E-codes. If it is assumed that the distribution of missingness is completely random and 10% of missing records are due to fire-related burn injuries, the yearly average (during 2010–2014) totals to 793 visits and some 224 patients. Among these, 169 patients would be of working age.

In 2011, outpatient visits for specialised health care cost an average of EUR 295.80 in the field of surgery and EUR 268.60 in the field of neurology (THL 2019). Using these figures and an estimate of fire-related burn injury visits (n = 793) gives a total cost of EUR 234,600. Similarly, fire-related combustion gas poisonings with an estimated number of visits of n = 148 give a total cost of EUR 39,800. Direct outpatient costs therefore equal approximately EUR 277,000 annually, which is a conservative estimate as a (small) fraction of fire-related injuries can be injuries other than burns or combustion gas poisoning. It should be noted that some of these outpatient visits may be also included among those treated through inpatient care. However, this is not double counting as inpatient visits are assessed in a separate study that excluded outpatient care. A case involving outpatient care but no admission to inpatient care could lead to some one or two weeks of sick leave (Jyrki Vuola, personal communication, 2016) with approximately EUR 780–1550 in lost earnings, and therefore lost productivity, based on the private sector monthly salary given by SF for 2015 (SF 2014).

9. DISCUSSION

9.1. THE EPIDEMIOLOGY AND A DESCRIPTION OF FIRE-RELATED INJURIES

A nationwide overview of fire-related injuries during 2000–2009 revealed that on average some 300 cases annually require inpatient care. Four out of five cases are burn injuries while the rest are mainly combustion gas poisonings. In addition, during the same period, nearly 100 fire-related deaths occurred annually. Most fatal cases take place at the site of the accident (Kokki 2011) and therefore do not appear in inpatient data. In-hospital mortality accounts for approximately 6% of the inpatient cases. Surveys performed in different countries have shown that burn injury–related in-hospital mortality is highly variable, ranging from 1.4% to 34% (Brusselaers et al. 2010). Different studies on burns reported lower in-hospital mortality rates than in the present study. The rates were 1.7%, 3.2% and 4.4% in England, Netherlands and Portugal respectively. However, our study focused on fire-related burns, and fire-related burns commonly tend to be more severe and deeper than those from other causes (e.g. from scalds).

There was no linear time trend for fire-related injuries in general, but two opposite sub-trends emerged: a decline in fire-related burns and an increase in combustion gas poisonings.

An increase in the mean age of patients was observed during the study period. This is consistent with the results of a previous Finnish regional study (Papp 2009) that disclosed an increase of the median age among burn patients admitted to the Kuopio burn centre during 1994–2006. Papp hypothesised that this upward trend could be at least partially due to the aging of the general population. However, a higher mean age can also result (at least partially) from a decreasing prevalence among young people. These findings of decline are in agreement with a study about burns requiring inpatient care in Sweden (Åkerlund et al. 2007). After all, Finnish and Swedish societies have somewhat similar socio-cultural backgrounds and welfare and health care systems.

The reason behind the decline of fire-related burns among the younger age groups remains a matter of speculation. Changes in smoking habits may, at least partly, play some role in the issue. The prevalence of smoking has decreased in Finland (from 2007 to 2012) in the age group of 25-54 in both males and females. However, the decreases are in the ball park of 5 units of %. On the contrary, somewhat similar increase was observed in the age group of 55-64 in both males and females (Jousilahti and Borodulin, 2012).

There is no conclusive evidence on the role of improved safety awareness among the young or enhanced product safety. Downward trends are likely to not be linked to biased recording practices; recording of the E-code was inadequate immediately after the introduction of the ICD-10 classification system in Finland, but it improved and stabilised just before the beginning of the present study period (Lunetta et al. 2008; Haikonen et al. 2013). Åkerlund et al. (2007) have hypothesised that "changes in safety regulations in schools and at work, a concentration of preventive measures that would mainly affect the younger population" at least partially explain the declining trend among the young. Interestingly, a decreasing trend has also been observed among various other severe injuries. For instance, Shinoda-Tagawa et al. (2003) observed (in the US, in 1970–2000) declining trends among all injuries within young males. They supposed preventive strategies may have been less effective in older age groups or focused more on younger people.

On the contrary, fire-related combustion gas poisonings displayed an upwards trend. The reasons behind this can only be hypothesised. An improvement in diagnostic accuracy may play some role. A possible factor could also be changes in furniture and interior materials that mean that they can produce more toxic fumes while burning. This was suggested in a Japanese study by Kaita et al. (2018). Similarly, McKenna et al. (2018) observed that flame retardants in furniture in the UK, although resulting in furniture burning more slowly, can produce significantly more toxic gases than furniture with no flame retardants.

In Finland, the majority of fire-related injuries are accidental. The proportion of self-inflicted burns was some 4%, which is in line with a previous Finnish study focusing on self-inflicted burns (5.7% of burns were self-inflicted, of which 82.1% were flame burns) (Palmu et al. 2004).

It is intuitive that the treatment of burn injuries is more burdensome than that of combustion gas poisonings. Burn injuries are more often treated at a university hospital and the lengths of stays are significantly longer. Half of the combustion gas poisonings could be treated within a one-day stay while for fire-related burns it was one week, ranging from one day to hundreds of days in the most serious cases. The situation of fire-related injuries manifesting as burns and combustion gas poisonings has two important parallel aspects; the majority of fire-related injuries are burn injuries, but the majority of fire-related deaths are due to toxic combustion gases. Therefore, combustion gas poisonings as an entity should not be dismissed as being less important component of fire injuries.

A sample from the Helsinki Burn Centre was obtained with all available fire-related burns in order to assess the effect of TBSA and aetiology. The mean (median) TBSA was 21.7% (15.0%) in the sample. The most severe injuries were caused by house fires compared to those caused by campfires, incineration, flammable substances etc. House fires were associated with older age (with victims being late middle aged or elderly) while campfires, flammable substances, barbecues etc. were more prominent in young people. Therefore house fires in general pose more serious treatment problems due to the severity of the injuries and patients' age (and therefore their poorer potential to recover) (Pomahac et al. 2006; Pham et al. 2009). The TBSA in the Helsinki Burn Centre was of a range within those reported in the medical literature. Among HICs, the most comparable data on TBSA were those from Canada and Australia (22% and 19.6% respectively) (Ahn and Maitz 2012; Banfield et al. 2015). An Indian study observed a mean TBSA as high as 42% (Ahuja and Goswami 2013) while it was only 8.8% in a Chinese study (Kai-yang et al. 2009).

9.1.1. CHALLENGES IN THE CORE DATA

At first, the feasibility of the core data (from the FHDR) was assessed in order to verify whether it could be used as a basis for the studies. The inadequate classification of injuries by means of ICD E-codes was the main previously documented issue. The completeness of coding was poor shortly after the ICD-10 classification system was introduced in Finland in 1996, but it improved markedly after the year 2000 (Haikonen et al. 2013). Therefore, such concern guided the decision to only use the FHDR as core data from 2000 until 2009. At the time the study was initiated, 2009 was the latest available year for which data were available. Additionally, possible re-admissions to inpatient care posed a challenge; how long a period of time should elapse since the previous admission in order to determine whether or not it refers to a new injury? Such a period of time was deemed to be at least two years. As a matter of fact, we used 10-year period in the epidemiological part of our study although two years was used when assessing costs. This was because the studies were executed simultaneously, but the minimum time limit was not yet determined for the epidemiological part, and therefore conservative estimate was applied. After all, several consecutive, new, fire injuries for one individual are probably very rare. The FHDR data consists of records for each stay at a specific ward. There are often multiple records concerning the care of a patient because transfers between wards in hospitals / health centres occur. In the case of an injury (a burn injury), these transfers are usually close or consecutive in time with no significant time lapse between transfers. This may not be the case for other medical conditions, such as heart disease. Through FHDR data, we had access to all the records, allowing full surveillance of the patient's care episodes to be conducted. This provides superior knowledge compared to conventional one-centre studies where only the stay in a particular centre is considered.

9.2. INDIRECT COSTS (PRODUCTIVITY LOSSES) OF FIRE-RELATED INJURIES AND DEATHS

9.2.1. INDIRECT COSTS OF DEATHS

The aim of this sub-study was to examine the indirect costs of fire-related deaths in terms of productivity losses and lost life years. On average, annual productivity losses due to fire-related deaths reached approximately EUR 31.1 million and 2763 years of life were lost.

In addition to being country specific, productivity losses are heavily dependent on the methodology used (i.e. the HC method, the FC method, the willingness-to-pay method). The standard HC approach was used to obtain monetary estimates of lost productivity due to premature deaths caused by fire. Our data also contained information on income and occupational status and therefore allowed us to use HC approach with assumptions based on the actual data rather than, for example, population mean values. For example, the employment participation rate differed from those of the general population (ca 70% in the general population vs ca 35% among 18–50 year olds and 16% among 51–65 year olds in the study population). It was observed that the victims of fire are often socially disadvantaged, which is consistent with a previous Finnish report by Kokki (2011) and an UK study by Mulvaney et al. (2009). As fire victims tend to be socioeconomically disadvantaged, limited productivity losses ensue.

Our estimate for productivity losses due to overall fire-related deaths was smaller than that provided by the US source WISQARS™ (CDC 2019): EUR 315,000 vs USD 800,000 (EUR 576,000 on 31.12.2010). If the information on the labour force participation rate were discarded and, instead, parameters from the general population were used, the Finnish estimates would come closer (EUR 530,000) to that of WISQARS™. The differences are therefore probably related to the victims' socio-economic profiles differing between Finland and the USA.

A Swedish study assessed the value of statistical life (VSL) using the willingness-to-pay method and suggested that the VSL for fire deaths would be 2/3 of traffic deaths (Carlsson et al. 2010). The Finnish Transport Agency reported value of lost life due to traffic accidents to be EUR 1.9 million in 2010, implying that, using VSL as a method for calculation, for fire death this value would be some EUR 1.25 million.

However, our approach was to estimate the economic burden strictly from a tangible point of view instead of pursuing higher numbers with methodologies where intangible costs are considered. Even though popular and widely used, the standard HC approach has been criticised for not covering all aspects of lost life. The approach also involves the choice of the discount rate, which yields non-negligible differences in the outcome as is evident in our analyses which were conducted using three alternative discount rates. Despite all of this, the standard HC method provides indisputable, objective measures based on life expectancy, labour force participation activity and projected earnings (Landefeld and Seskin 1982). Therefore, the estimates could be considered conservative values of the burden as all intangible burdens are omitted.

As a matter of fact, the HC approach is not even the most conservative way to valuate losses. The FC method only considers the lost productivity during the time that the deceased is yet to be replaced by a new worker, which obviously leads to lower estimates than those gained by the HC method as the friction time to replace a worker is usually some months rather than the remaining life course that is utilised in the HC approach.

If one wishes to disregard our observations on the victim's socio-economic status, an inflation factor of 1.7 could be used to calculate estimates corresponding more towards the parameters of the general population. This factor is the ratio between losses calculated with the parameters of the general population and losses calculated with parameters observed in the specific population of the study.

The PYLL value was additionally used to measure the burden as it is commonly reported in burden studies. It is straightforward to interpret. The average PYLL has declined in the period 2000–2010, which means that less young people are dying from fire and the age distribution is shifting to older ages. Total annual PYLL did not exhibit a trend similar to the average PYLL. However, in addition to age distribution, total PYLL depends on the annual number of deaths, which varied between 74 and 125 per year in the study period. If the shifting of age distribution to older age persists, PYLL should show some decline, which would reflect a reduced burden of productivity losses in the future.

So far preventive measures have been legislative, mainly focusing on the introduction of self-extinguishing cigarettes and mandatory fire alarms, as well as on improving risk assessment (Kokki 2011). According to more recent available data from the fire and rescue services (Kokki 2014), a reduction of fatal fire-related deaths has ensued from the introduction of fire-safe cigarettes in 2010; the total number of fire-related deaths reached an all-time low (59) in 2013. The collection of detailed data on the circumstances of a fire and the characteristics of fire victims, as well as data on the activities of rescue services, has guided the actions of the fire and rescue authorities and has contributed to improving the equipment and self-preparedness of fire and rescue services (PRONTO 2019).

The quality of core data for fatal cases is high; the SF cause-of-death statistics are nationwide, cover virtually 100% of the resident population and are based on the results of a medicolegal autopsy. A full post-mortem toxicological analysis, including measurement of COHb and cyanide, is performed in nearly all out-of-hospital deaths (expert opinion, Philippe Lunetta, forensic pathologist, Finland)

9.2.2. INDIRECT COSTS OF INPATIENT INJURIES

In Study V the burden of fire-related injuries in terms of lost productivity due to disability was assessed. Lost productivity gives a societal perspective through indirect costs. Lost labour productivity, as well as diminished household work productivity, was included in lost productivity. We calculated productivity losses to be EUR 28.6 million during the period of 2001–2005 with a mean loss of EUR 19,070 per patient.

Some 27% of the overall patients were deemed to have received some benefit post-injury, which corresponds to 35% among the working age people. This figure is very similar to that for fire-related deaths when comparing the labour force participation rate. Records of benefits were linked to each patient by using burn injury or combustion gas poisoning diagnoses and/or temporal connections. Some benefit records were missing a cause indicator so it may be that not all relevant cases were captured by our methods if benefits were granted after inpatient care. It was challenging to assess the loss of productivity as a considerable proportion of patients could not be deemed to have received any benefit and therefore no proxy for an estimate of disability duration was available in those cases. This should be considered as a major limitation of this study. It is obvious that each injured person is disabled for a certain period of time regardless of whether they had been working (i.e. they received post-injury benefits) or not. The challenge was how to handle such cases without recorded benefits. While having no conclusive information, imputation of the expected period of disability was used as a remedy. The mean values of disability duration in inpatient time groups among those who had recorded benefits were imputed for corresponding inpatient time groups among those with no recorded benefits. Additionally, the disability time was calculated by dividing the estimated duration in days by 365, therefore not taking into account possible holidays.

Research on indirect costs and the burden of non-fatal fire-related injuries is scanty. Our earlier reporting (Study III) assessed direct inpatient costs due to fire-related injuries. The present study assessed the indirect burden of these injuries as lost productivity. A Dutch study addressed the working-age patients admitted to Rotterdam burn centre from August of 2011 to July of 2012. Of those who were pre-employed, 70% had returned to work by three months and 92% had returned by 12 months while 8% had not returned by 24 months, which was the duration of the follow-up period (Goei et al. 2016). In our present study, half of assumingly pre-employed patients had recovered within just over two months. In another Dutch study, burn injuries were followed up for three months. It appeared that flame burns were significantly more burdensome than other types of burns (Hop et al. 2016). In this Dutch study the lost productivity during this period cost on average EUR 5000 per patient, which is substantially less than our estimate, but our follow-up time was much longer (i.e. 5–10 years). Additionally, the Dutch authors used the FC method which, as previously discussed, produces lower estimates than the HC method.

The assessment of allowances in this study is conservative as it omits, for example, housing allowances and discretionary social assistance, which would be likely to cumulate to a considerable amount. However, benefits are not considered societal costs and therefore are of limited interest considering the scope of the study. However, they were treated as proxy defining the time of lost productivity. Additionally, a minor underestimation of the indirect cost of non-fatal injuries can also be related to the lack of E-codes or the use of an unspecified code in the FHDR. This figure has been some 5–10% of burn injury admissions, of which a fraction could be unidentified fire injuries.

9.3. DIRECT COSTS OF FIRE-RELATED INJURIES

9.3.1. DIRECT INPATIENT CARE COSTS

The direct inpatient costs of (severe) fire-related injuries in Finland were examined. On average there are annually some 300 fire-related injuries leading to inpatient care, yielding EUR 6.2 million in care costs. Nearly 80% of the cases are burn injuries, the rest being mostly combustion gas poisonings. Injuries involving burns are more burdensome than combustion gas poisonings in terms of care: the lengths of stays are significantly longer and treatment often takes place in university hospitals. Inpatient care costs of combustion gas poisonings totalled a mere EUR 0.19 million annually in contrast to the EUR 5.9 million cumulated by burn injuries.

The mean cost of a fire-related burn injury was EUR 25,400 while the median was EUR 6700, indicating the cost distribution is skewed to the right. In a US study (Milenkovic et al. 2007) the estimate of mean cost was somewhat lower (USD 17,300) as it was also in a Norwegian study (EUR 11,800) (Onarheim et al. 2009). This may be partly due the fact that our study focuses on flame burns, which tend to be more demanding in terms of care than, for example, the more common scalds. Moreover, our method captures the whole episode of care including all transfers between wards and hospitals, not just the initial burn centre stays. A Canadian study assessed fire-related burn patients during 1995–2012 with an average TBSA of 22% (Banfield et al. 2015). In this study, the cost estimate was some US$ 76,600. However, the average TBSA of 22% reported in Canada is likely to be substantially higher than the average Finnish TBSA. Although in Finland no nationwide data on TBSA are available, the main burn centre in Finland (in Helsinki) exhibited a mean TBSA of nearly 22%. Therefore the nationwide TBSA figure is expected to be significantly lower as the most severe cases are treated in burn centres. A Dutch study by Hop et al. (2016) came close to our estimate of care costs: EUR 21,000. In their data, almost 40% of the burns were fire-related. On the other hand, in LIC care costs may appear very low by western standards. For example, in Malawi, the average care cost was merely US$ 560 among patients with a mean TBSA of 17.9%.

There are studies that have assessed care costs and focus on a limited number of patients. A Welsh study (Hemington-Gorse et al. 2009) examined three patients with severe burns that had 27% TBSA, 38% TBSA and 48% TBSA. The care costs for these cases amounted to EUR 121,496, EUR 485,384 and EUR 761,205 respectively. In an Australian study, the care costs of 20 burn patients were studied. The highest cost occurred for a patient with 62% TBSA and amounted to AUD 842,419 (EUR 662,540 on 1.1.2012). These studies show that extreme care costs are similar to those observed in our study where, in some cases, costs exceeded EUR 0.5 million.

As %TBSA is a key factor in determining the care costs (McMillan et al. 1985; Ahn and Maitz 2012), the crude relation of %TBSA to the burden of burns was assessed. The mean number of inpatient days per %TBSA was 2.7 days (the median being 1.6 days) per %TBSA. Monetarily, this corresponds to EUR 3000 per %TBSA on average with EUR 2120 as the median. The treatment of very large burns (i.e. >50 %TBSA) requires substantially more resources per each %TBSA than small burns. This indicates that the burden may increase faster than being a linear increase as %TBSA increases. This was reported by McMillan et al. (1985) in regard to the costs of an operating room for a burn injury.

The extent of a burn measured as %TBSA is, however, not the only factor that determines the care costs. Even though %TBSA is an important prognostic factor, it does not distinguish the location and depth of the injury, both of which may significantly affect the care costs. Moreover, older age is associated with comorbidities and delayed wound healing, resulting in an increased burden of care (Wibbenmeyer 2001; Pham et al. 2009). The age effect was confirmed in our study; those aged 60 years old and older exhibited a two- to three-fold cost per %TBSA compared to the younger patients. However, the method used for assigning care periods for an injury captures all continuous inpatient care including concomitant medical conditions. In other words, our method also captures comorbidities occurring during the episode and care in any ward, not just the burn centre stay. As a result, medical conditions aggravated by a fire-related injury are captured as consequences of the injury and taken into account as a burden.

The burden of care for combustion gas poisonings is significantly lower than that of burn injuries. The average nationwide care cost for combustion gas poisoning was estimated at EUR 3600. This is a significantly lower estimate than those previously reported; Iqbal et al. (2012) came up with estimated cost of US$ 11,381 for CO poisonings unrelated to fire in the US. Another two US studies (Ran et al. 2017; Miller and Battacharya 2013) estimated care costs ranging between US$ 9,554 and US$ 15,769. A Turkish study (Sut and Nemis 2008) estimated an average intensive care cost for CO poisoning at US$ 1062. Due to the limited number of studies addressing the burden of combustion gas poisonings, especially those due to fire, it is difficult to get an adequate overview of the burden of such injuries. Overall, at least in a Finnish setting, the burden of care due to CO poisoning is only a marginal fraction of the burden of flame burns. It is even so that one severe flame burn may cost as much as all the combustion gas poisonings in a year together.

It has been shown that the FHDR has some underreporting in E-codes. Despite clear progress in using the E-codes, some 10% of the inpatient stays with a burn injury still lack the E-code that is needed for identifying the circumstances and cause of the injury. Some 55–60% of the burn injuries are coded as being due to other factors than fire-related burns (Haikonen et al. 2013). In this aspect, underestimation of fire-related cases can be approximately 5%. Another drawback is that the FHDR does not include information on TBSA or on exposure measure for combustion gas poisoning. Therefore, the assessment of the effect of TBSA was limited to patients treated in the Helsinki Burn Centre.

9.3.2. OUTPATIENT (UNPUBLISHED DATA)

Outpatient care due to burn injuries may present a significant burden. However, due to data quality issues with respect to E-codes, the analysis on outpatient admissions in specialised health care could not be as reliable as in the case of inpatient care. During 2006–2014, annually, on average, some 2420 patients required outpatient care for a burn injury. As each patient had an average of three visits per year and approximately 7260 visits occurred annually. Among combustion gas poisonings there were, on average, 288 patients annually. Data on fire-related cases were only examined for the period 2010–2014 in order to minimise the issue of E-code underreporting which was observed before 2010. The number of patients with fire-related burn injuries could be some 224 annually (with 793 visits) and for patients with fire-related combustion gas poisoning, around 137 patients (with 148 visits). Valuing the visits with a corresponding health care cost, these visits yielded in total EUR 234,600 for fire-related burns and EUR 39,800 for fire-related combustion gas poisonings, which gives a total annual direct cost of EUR 277,000. This represents approximately 4% of the direct costs due to inpatient care. Unfortunately, no data were available to assess fire-related injuries treated in primary health care. It is customary that on many occasions, for every inpatient there are multiple outpatients. However, according to our data the number of outpatients in specialised health care in relation to inpatient care is limited. It could be that in case of a burn injury due to fire, the consequences tend to be more serious than, for example, scalds, inhibiting the amount of outpatient care in relation to inpatient care. The low proportion of flame burns in outpatient visits has also been observed in other countries (Taghavi et al. 2010; Gabbe et al. 2015). All in all, it seems that focusing on more severe cases in terms of direct costs is more effective considering the difficulties in obtaining high quality data for minor fire-related injuries. However, also assessing the costs of minor fire-related injuries would be relevant for comparing them with those of inpatient cases.

In terms of indirect costs, an injury managed with outpatient care exclusively may still be serious enough to warrant a brief sick leave and therefore exhibit a productivity loss manifesting as an indirect cost. The duration of such a sick leave has been crudely estimated to be one to two weeks (personal communication, Jyrki Vuola, 2015). This corresponds to a productivity loss of EUR 780–1550 by using the private sector monthly salary in 2015. To assess these losses at a national level one would need to know what fraction of the injured were workers and therefore productive. As shown in the study of fire-related deaths, the socio-economic profile of fire-related victims significantly deviates to that of general population, at least in the case of deadly events.

9.4. LIMITATIONS AND STRENGTHS

The present study is based on register data. Such data is administrative in nature and is not originally developed purely for research purposes. The core data was derived from the FHDR. It is well known that FHDR data are not entirely accurate for injury research (Lunetta et al. 2008; Sund 2012). For a relatively short period, following the introduction in Finland of the ICD-10, external cause-of-injury coding (E-code coding) was significantly neglected. However, our assessment covering the period 1996–2009 revealed that the underreporting of E-codes in the FHDR has considerably declined since 2000, as has the number of missing and unspecific codes (Haikonen et al. 2013). An additional general limitation in performing a register-based study is that it is retrospective in nature and therefore only allows for acquiring a limited amount of information on a given topic. Benefit records were also affected by the underreporting of ICD codes and may not be completely accounted for in the analyses despite the application of temporal matching. Additionally, the majority of patients did not exhibit any benefit record. Such a large proportion of missing information on the length of disability time was a major drawback and required the use of imputation simply based on the length of hospital stay, which was known for each patient. Therefore, the study on productivity losses due to fire injuries is less accurate and of lower quality compared to our other studies on the burden of fire-related injuries. In addition, the FHDR does not include information on TBSA, even though TBSA is a major prognostic factor that may affect the duration of care and therefore the costs. This limitation was somewhat alleviated by collecting a representative sample (all the fire-related cases during a five-year period) of flame burn patients from the Helsinki Burn Centre, where TBSA information is recorded on patient files.

The use of register-based data also has some strengths. For example, unlike survey samples, register-based data is not subject to recall bias. The coverage issues arising in one-centre studies are avoided as the FHDR is a nationwide register covering all of the care provided in wards across the entire country. Patients have unique personal identifiers which remain constant over time. This enables the follow-up of treatment episodes involving transfers from wards or hospitals (i.e. burn centres) to other locations. Unlike one-centre studies, where only care in a specific ward is recorded, it allows the depiction of the entire care process and therefore captures the burden more comprehensively.

Due to a lack of data, injuries treated through outpatient primary health care could not be assessed. However, since fire-related burns are often more serious than burns caused by other mechanisms, this probably does not amount to a large fraction of very significant injuries. Notwithstanding, the epidemiology of mild burns treated in primary health care for outpatients may differ from those treated in specialised health care. For instance, a study on outpatients treated in a burn centre in Tehran (Iran) (Taghavi et al. 2010) revealed the commonest causes of injuries were hot liquids or steam (55%) while flame merely accounted for 0.6–13.3% of the cases, depending on the age group. A study based on data from Australia and New Zealand compared outpatient admissions to inpatient care (Gabbe et al. 2015). In the outpatient setting, the proportion of flame burns was 17.4% while it was 41.6% among inpatients. These suggest that flame burns are present less frequently as mild injuries.

The exceedingly high rate of medicolegal autopsy and post-mortem toxicology in Finland in regard to injury deaths, including those fire-related, ensures the accurate diagnosis of cause of death and guarantees the reliability of SF mortality data. It allows, especially in out-of-hospital deaths, the discrimination between deaths due to combustion gas poisoning and those due to a burn injury, and provides clues on the role of alcohol use as a contributing factor to fire-related deaths.

Human Capital method was used in determining indirect costs in form of lost productivity due to fire injury / death. The method has been criticised for not account for all aspects of losses. Additionally, the method is sensitive to the choice of discount factor, which means that estimates based on several factors are often provided. However, we do not claim to have accounted for all aspects of losses but rather the key tangible component in a societal perspective; the lost productivity. Finally, "the standard HK [HC] approach has the virtue of providing numerical estimates that are indisputable measures of what they say they are: objective numbers based on life expectancy, labor force participation, and projected earnings" (Landefeld and Seskin 1982).

10. CONCLUSIONS

The burden due to fire-related fatal and non-fatal injuries in Finland is considerable. During 2000–2010, an average of 99 people died annually, causing more than EUR 31 million in productivity losses per year while 300 were injured severely enough to be admitted for inpatient care. Inpatient care generated annually more than EUR 6 million for direct care costs and some EUR 5.7 million in productivity losses. Recent nationwide statistics in Finland have revealed a considerable decrease in the number of fire-related deaths of roughly one quarter compared to our study period, but the mortality remains high compared with most other HICs. The goal set in a Finnish safety programme of reducing the number of deaths to 50 at maximum by 2015 has not been achieved so far. Of the 300 fire-related injuries that required inpatient care, some 80% were severe burns. Our method of capturing the whole episode of care yielded on average nearly three weeks of hospitalisation for fire-related burns, a more accurate estimate than those of one-centre studies in which only the stay in the centre is usually considered. If survived, a very severe burn may yield hundreds of thousands of euros worth of care costs, topped with significant amount of potential lost productivity.

The implications of this for prevention are not clear cut. In victims of all ages, alcohol use seems to remain as one of the most important single contributing factor of deaths. Alcohol abuse in domestic settings could be a target of primary prevention, together with environmental risk factors.

Age is an important factor, playing a role in cost accumulation as well as being a risk factor. Preventing deaths among young people would obviously avoid more productivity losses than preventing them among the elderly. But the majority of the victims were not young. In fact, among non-lethal fire-related injuries, the greatest care costs were caused by the elderly since their treatment requires more resources and they have less ability to recover. A specific cause of fire-related fatal and non-fatal injury stands out from the others: residential fires. On average, the extent of burn injuries caused by house fires is much greater than for those caused by other mechanisms. Those injured in house fires are often in late middle age or older. Together with extensive burns, these injuries result in a much higher burden than other causal mechanisms. Most fire-related deaths are also due to house fires. Moreover, thousands of structural fires, which cost millions of euros in property damage, occur on an annual basis. Overall, cost–benefit assessments could be implemented in order to come up with cost-effective means to prevent these injuries and deaths. It seems that house fires should be a primary target in prevention.

Risk of fire injury may be reduced by reducing incidence of fires per se. The implementation of self-extinguishing cigarettes seems to have reduced fire related deaths by way of reducing fires ignited by cigarettes. Reduction in smoking prevalence may also play a role in this aspect. It's to be followed whether these factors further reduce fire incidents. Another important factor is smoke alarms. In Finnish settings it was estimated that in some half of the cases of severe fire injuries no smoke alarm was present. Functioning smoke alarm indicates the fire before it fully advances and permits early fire suppression or at least exit without severe injuries. It's required in Finland for a new built property to have smoke alarms installed utilizing electric power network. However, the benefit of this likely realizes in longer term. Yet another highly effective method in terms of preventing fires is sprinklers. A report from Canada revealed that the death rate of non-sprinkled fires were 13.7 times of that in sprinkled fires and injury rate 1.5 times respectively (Garis et al. 2017). Installing sprinkler systems in existing structures might be insurmountable investment for many but incorporating it to new construction production could be beneficial and more acceptable although the benefits, in this case too, would realize in longer term as opposed to self-extinguishing cigarettes which yield impact rapidly.

Population ageing poses challenges in fire safety, as well as in health care, as the treatment of the elderly is more expensive and aged patients have poorer ability to recover. Moreover, the elderly are at a greater risk of dying from milder injuries than the young. Declining and reduced psycho-motor functions, and cognitive abilities and skills in the elderly and subjects under the influence of alcohol and other drugs are major risk factors for fire injuries.

Directions for future studies emerged. In addition to alcohol, studies should also ascertain the role of other drugs in reducing psychomotor and cognitive abilities and skills prior to and during residential fires. Moreover, given the high frequency of alcohol-associated fatal cases, studies on the role of alcohol should be extended to non-fatal burn injuries. Improving data collection on admissions would also allow the assessment of the impact of alcohol on the clinical course of burn injuries

Injuries and deaths seem to have declined among the young but not among the elderly. The causes and circumstances among the elderly could be scrutinised, and the functional capacity and the associated factors screened. In addition, a disturbing finding was the increasing trend of combustion gas poisonings. This could be a target for research and have implication for further studies; is there a connection with population ageing? What is the underlying cause? Additionally, the study only addressed concrete, tangible costs from a societal point of view, yielding conservative estimates. For a more complete approach, the investigation of intangible costs and property losses could be incorporated in parallel to our estimates, allowing for more comprehensive cost–benefit analyses. Obviously, if a preventive measure turns out to be cost-effective by using our scale of estimates, it would certainly be so when also incorporating intangible components.

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11. ACKNOWLEDGEMENTS

This study was carried out at the National Institute of Health and Welfare (THL) and at the University of Helsinki, Finland during the years 2011-2020.

I wish to express my deepest gratitude to my supervisors Docent Pirjo Lillsunde, Ministerial Adviser, Ministry of Health and Social Affairs and Professor Philippe Lunetta, Department of Forensic Medicine, University of Helsinki and University of Turku, who have introduced me to scientific research, for their continuous advices and constructive criticisms through this research project. Without their encouragement and enormous support, this study would have not been possible.

I want also to express my sincere gratitude to Professor Jyrki Vuola from the Helsinki Burn Centre, Helsinki University Hospital, for his constant support and interest towards my research work. It has been a great privilege to share Jyrki's extensive professional knowledge in the field of burn injuries.

A special acknowledgement goes to Professor Reijo Sund, Institute of Clinical Medicine, University of Eastern Finland. His active participation and guidance in the methodological part of the study, significantly improved the quality of the present study. Dr. Esa Kokki, Emergency Services College, Finland, is gratefully acknowledged for sharing his great expertise in investigating and assessing fire-related deaths.

My special thanks go to Professor emeritus Erkki Vartiainen, National Institute for Health and Welfare, and Vesa-Pekka Tervo, Senior Inspector, Ministry of Interior, for their precious inputs in the early phase of this study project, to Dr. Anne Lounamaa, Head of Welfare and Health Promotion Unit, National Institute of Health and Welfare, for her constant support throughout the work of the thesis, and to Professor Ossi Rahkonen, Department of Public Health, University of Helsinki for his support in coordinating the study.

I wish to warmly thank Dr. Antti Impinen, National Institute of Health and Welfare, for our many coffee table conversations and inspirational discussion on handling research data. My special thanks are also due to Sakari Kääriäinen and Janne Sysi-Aho for skillful assistance in collecting original data.

The manuscript was reviewed by professor Tiina Laatikainen, University of Eastern Finland, and professor Pekka Rissanen, National Institute for Health and Welfare. I am most grateful for their valuable comments and criticisms, which significantly improved the final version of the thesis.

I am honoured professor Antti Sajantila, Department of Forensic Medicine, University of Helsinki, accepted the role as kustos in my dissertation.

This study was financially supported by the Finnish Fire Protection Fund and the National Institute for Health and Welfare. Without their support the study could not have been conducted.

In memoriam of my beloved father Vesa who passed away much too young. You were always there for us.

Helsinki, April 2020

Kari Haikonen